Chapter 8

Nutrient management guidelines for some major field crops

Practical recommendations and guidelines on nutrient management for specific crops are usually provided by the local research and extension services in each country. This is logical and also necessary because of the crop- and area-specific nature of such recommendations. The IFA (1992) has published examples of practical nutrient management guidelines for almost 100 crops in major countries where these are grown. There are also numerous publications on this aspect at regional and country level. Overall guidelines on the management of nutrients and their sources (mineral, organic and microbial) have already been provided in Chapter 7. The present chapter provides some crop-specific information on nutrient management including diverse nutrient sources as part of INM. Again, extension workers or farmers should seek the information relevant to their conditions from local sources and their applicability to local socio-economic conditions. The guidelines given below should be seen in the nature of illustrative information in order to appreciate the importance of balanced crop nutrition for sustaining medium to high yields of crops.

CEREALS AND MILLETS

Wheat (Triticum aestivum L.)

Wheat is the most widely grown cereal crop in the world. It is cultivated on almost 215 million ha out of 670 million ha under cereals. Wheat grain contains 70 percent starch and 12–18 percent protein. The highest grain yields are obtained with winter wheat. These range from 1 tonne/ha to more than 12 tonnes/ha, with a world average of about 3 tonnes/ha. High yields (up to 14 tonnes/ha) can be obtained from highly productive varieties with appropriate nutrient and crop protection management on fertile soils with adequate water supply. Globally, wheat yields have increased considerably as a result of breeding programmes that have incorporated the short-straw trait from Mexican varieties. Such varieties are more responsive to applied nutrients and are also more resistant to lodging as compared with the local wheat varieties.

Wheat can grow on almost any soil, but for good growth it needs a fertile soil with good structure and a porous subsoil for deep roots. The optimal soil reaction is slightly acid to neutral although it can be grown successfully in alkaline calcareous soils under irrigation. The water supply should not be restrictive and rains should be well distributed.

Nutrient requirements

The amounts of nutrients required can be derived from soil testing and the nutrient removal by grains and straw. A crop of winter wheat producing 6.7 tonnes grain/ha absorbs an average of 200 kg N, 55 kg P_2O_5 and 252 kg K_2O/ha. Under subtropical Indian conditions, a crop producing 4.6 tonnes grains + 6.9 tonnes straw absorbed 128 kg N, 46 kg P_2O_5, 219 kg K_2O, 27 kg Ca, 19 kg Mg, 22 kg S, 1.8 kg Fe, 0.5 kg Zn, 0.5 kg Mn and 0.15 kg Cu. The proportion of nutrients absorbed that ends up in the grains is 70 percent in the case of N and P and 20–25 percent in the case of K. For winter wheat, the nutrient requirement before winter is small. It is highest during the maximum vegetative growth in spring. More than 80 percent of the nutrients are taken up by ear emergence. Where organic manure is used, it should be applied before sowing or, if applied carefully, as slurry during early growth. Nutrient requirement varies considerably depending on the soil fertility, climate conditions, cultivar characteristics, and yields.

Macronutrients

In temperate regions, 25 kg N are required per tonne of grain containing 15 percent protein. Therefore, a yield of 10 tonnes will need 250 kg/ha N for the grains alone, and about 30–40 percent more for the total plant biomass, which results in a total amount of 350 kg N/ha. However, as fertile soils generally provide one-third of this amount, fertilizer amounts can be adjusted to N removal in grains. Ideally, N fertilizer applications to winter wheat (200–250 kg N/ha for high yields) should be split into several dressings as follows:

- in autumn: only 30 kg N/ha (or none where sufficient N is left from the previous crop);
- in early spring: about 120 kg N/ha (minus mineral N in soil, e.g. 30 kg/ha N);
- at beginning of tillering: about 30–50 kg N/ha;
- at ear emergence: 40–60 kg N/ha – this can be divided into two portions to enable a late foliar spray to improve protein content for better baking quality.

Wheat needs no special N fertilizer. However, for applications in spring with cold weather, quick-acting nitrate is superior to ammonium or urea. Placement of N fertilizers brings little or no advantage on most soils, except perhaps under low rainfall and in the absence of irrigation. One kilogram of fertilizer N produces about 15–25 kg of grain. Where yields are limited by climate or other constraints, the fertilization rate can be reduced in view of the lower requirements and the respective soil nutrient status.

Under subtropical conditions, the generally recommended amounts of N are 120–150 kg N/ha to irrigated HYVs, and about half of this to traditional varieties or where irrigation is not available. N application is generally recommended in 2–3 splits at planting, and one month and two months after planting. The basal dressing is generally given in the form of urea or through NP/NPK complexes. For top-dressing, any of the common N fertilizers are suitable but ammonium sulphate performs better than others on S-deficient soils. To unirrigated wheat depending solely on stored soil moisture and seasonal rainfall, N rates varying from 40 to 120 kg N/ha can be applied depending on stored soil moisture as described above (Figure 36).

Because an optimal supply of P and K is required for high yields, even during periods of water stress, these nutrients should be applied before sowing in spring or autumn unless there is danger of K leaching on sandy soils. As a rule, on fertile soils, nutrients applied to offset nutrient removal with grains and straw are sufficient. For a yield of 8 tonnes/ha of winter wheat, the recommended rates are: 90 kg/ha P_2O_5, 160 kg/ha K_2O and 25 kg/ha Mg. On deficient soils, the amounts added should be at least 30 percent higher, and on soils containing high amounts, about 50 percent lower than the values given above.

Deficiencies of nutrients other than NPK are likely to occur in poor soils, at high yields and with persistent use of NPK. S and Mg are the two most likely nutrients to be limiting. These can be applied prior to sowing or, in the case of S, through an S-containing N fertilizer in the standing crop. Where visible deficiency symptoms appear, water-soluble fertilizers or foliar sprays can be applied.

Micronutrients

For high yields, Mn and Zn may be in short supply in neutral to alkaline soils and Cu on sandy soils. Zn deficiency is generally a problem in coarse-textured soils under intensive cropping. Here, an application of zinc sulphate of 62.5 kg/ha once every 2–3 years is suggested. Zn deficiency can also be corrected by spraying 0.5-percent zinc sulphate (at a per-hectare rate of 2.5 kg zinc sulphate and 1.25 kg unslaked lime dissolved in 500 litres water). Generally, 2–3 sprays at 15–day intervals may be needed. In Mn-deficient soils, foliar spray with 0.5-percent manganese sulphate solution 2–4 days before the first irrigation and again 2–3 times at weekly intervals can be done on sunny days.

Rice (Oryza sativa L.)

Worldwide, rice occupies almost 150 million ha. A very high proportion of the world's rice is grown under the wetland system. This system consists primarily of submerged or waterlogged conditions for a major part of the growth period of the crops. Wetland rice soils vary greatly in their nutrient status. Regardless of their initial reaction, the pH of such soils moves towards neutrality after submergence. The general growth conditions and the fertilizer practices are influenced considerably by the anaerobic, reducing conditions in the flooded soil. These soils tend to have low organic matter and, therefore, they provide only a relatively small supply of N and P from mineralization unless green manured.

Nutrient requirements

Nutrient uptake and removal by rice is influenced strongly by the variety, season, nature and composition of the soil and the yield level. In order to produce 1 tonne of paddy (rough rice), the rice crop absorbs an average of 20 kg N, 11 kg P_2O_5, 30 kg K_2O, 3 kg S, 7 kg Ca, 3 kg Mg, 675 g Mn, 150 g Fe, 40 g Zn, 18 g Cu, 15 g B, 2 g Mo and 52 kg Si. Out of the total uptake, about 50 percent of N, 55 percent of K and 65 percent of P are absorbed by the early panicle-initiation stage. About 80 percent of N, 60 percent of K and 95 percent of P uptake is completed by the heading stage. The partitioning of uptake in the case of N and P is higher in grain than in straw (3:1), whereas greater proportions of K, Ca, Mg, Si, Fe, Mn and B remains in the straw. The S, Zn and Cu taken up is distributed about equally in straw and grain (Yoshida, 1981).

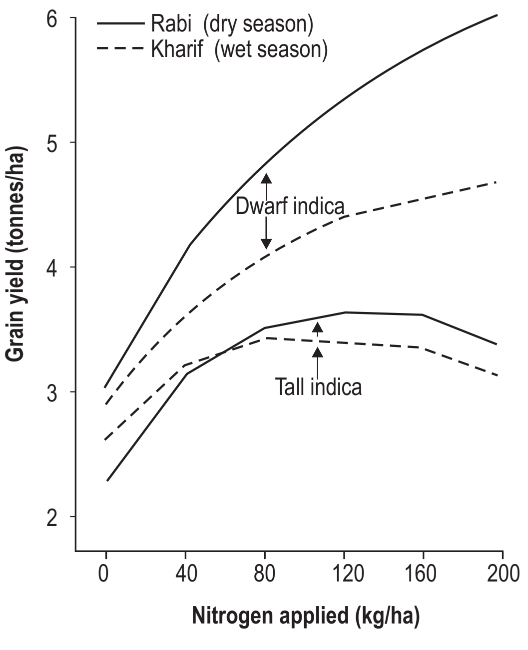
Macronutrients

There is a close association between the amount of N fertilizer applied to rice and the yield level. Yield responses of 20 kg or more of paddy or rough rice per kilogram of N are frequently obtained. The amount of N that can be applied to traditional, tall rice varieties is limited because of their susceptibility to lodging and low yield potential. However, the improved short HYVs that are resistant to lodging can benefit from a higher level of N supply (Figure 42). While traditional varieties could justify rates of up to 50 kg N/ha, 160 kg N/ha or more is recommended for HYVs under good management with assured water supply. The season of planting also influences the N requirement of rice. During the dry season, when abundant sunshine is available, the irrigated HYVs can justify 30–40 kg N/ha more than in the lower-yielding rainy season. Incorporation of a good green manure crop raised before planting rice can add 50–60 kg N/ha as well as a substantial amount of organic matter.

The timing of N applications is very important for improving the efficiency of N use by rice. The crop may require none or a modest basal application and up to three top-dressings in the standing crop in order to maintain the N supply throughout its growth. Split applications are especially important where total N requirement is high in order to avoid leaching losses (particularly on permeable soils).

The method of N application is also important for reducing N losses and improving the nitrogen-use efficiency the crop, which

FIGURE 42
Average yields of 4 dwarf and 7 tall indica rice varieties as affected by N fertilization



Source: Tanaka, 1975.

is often below 50 percent. The basal application should be worked into the flooded soil. The applications of ammonium or urea N should, where possible, be made into the reduced soil horizon. This is because broadcasting them into the floodwater is likely to result in high N losses. Placement of urea in the reduced zone can be facilitated by using urea supergranules. Nitrate-containing fertilizers such as AN or CAN are often less satisfactory for rice, particularly where given at or before planting. They can be used for top-dressing when crop uptake of nutrients is proceeding rapidly, and the topsoil is covered with a mat of roots, and thus, N losses are minimized.

Because upland rice relies mostly on rainfall and soil moisture reserves, rice yields are lower than in the case of wetland rice. As the soil under upland rice is not flooded, soil nutrient behaviour is similar to that in other upland cereal crops. Application of 50–100 kg N/ha can be justified, depending on yield potential. Total N should be split between a basal and a top-dressing. Owing to high leaching losses, upland rice can often suffer from N stress even where N is applied.

While the availability of soil P is improved by flooding, many old rice soils have a low P content because of crop removal over the years. This, together with the greater demand for P by improved varieties, makes adequate use of P fertilizer important. Optimal rates vary with local conditions, but 20–40 kg P_2O_5/ha is usually enough for traditional varieties and 40–80 P_2O_5/ha for improved varieties. In the intensive rice–wheat rotation, where wheat has been fertilized adequately, the rate of P application to rice can be reduced. This is because flooded rice can make better use of the residual P applied to wheat. Where two rice crops can be grown in succession within a year as in monoculture, the dry-season crop usually requires a higher rate of P application than does the wet-season crop. P should be applied as a basal dressing in order to promote root growth and tiller formation. Water-soluble P or a combination of water- and citrate-soluble P is normally most efficient for rice production. Many upland rice soils are low in available P, and moderate P applications are usually required.

The crop uptake of K is quite high but much of it remains in the straw. In traditional rice varieties, responses to K have usually been small. However, improved varieties usually respond to K, especially where given adequate N and P. Responses to K are generally greater on sandy soils. While 20–40 kg K_2O/ha may be sufficient for traditional varieties, improved varieties can justify the application of 60 kg K_2O/ha particularly on soils that are poor in K. On most soils, K fertilizer should be applied as a basal dressing. However, on free-draining sandy soils where leaching may occur, split application of K is being increasingly recommended. Potash fertilization should also keep in view the fact that, where K is cheaper than N and P, it can be equally profitable even at lower response rates.

S deficiency is becoming more widespread in rice. This is because of higher yields and, thus, greater S removals, the reduced use of organic manures, possible leaching of S and the widespread dominance of S-free fertilizers (urea, DAP and MOP) in the product pattern. Where either AS or SSP is a part of the fertilization schedule, the required S is often supplied through these sources.

Micronutrients

Owing to the intensification of rice production, micronutrient deficiencies are becoming more common. It is important to identify and correct them wherever they occur. Field-scale deficiency of Zn in rice was first discovered at Pantnagar in India. The deficiencies of Zn and Fe can occur fairly commonly in rice fields, especially on high pH soils, Fe more so in upland rice. Where Zn has not been applied to the nursery, 10–12 kg Zn/ha through zinc sulphate (21 percent Zn) can be applied before planting. It can be surface broadcast and incorporated before final puddling. Fe deficiency can be corrected by giving 2–3 foliar sprays of 1-percent ferrous sulphate at weekly intervals. Green manuring also reduces Fe deficiency.

Rice is unusual in responding to the application of Si (a non-essential beneficial element). Si in the form of soluble silicates and waste products containing Si is applied in some countries. It is thought that Si promotes growth by making soil P more readily available to the plants, by producing strong stems, by providing resistance against certain pests and by protecting the plant from Fe and Mn toxicity.

Organic and green manuring

The nutrient status of rice soils can be improved by applying organic manure a week or two before transplanting. Where adequate water is available, green manuring with a fast-growing leguminous plant is often recommended. A good green manure crop of *Sesbania* can add 50–60 kg N/ha where incorporated into the soil before planting rice. Details about green manuring have been provided in Chapters 5 and 7. Where a leguminous green manure such as *Sesbania* is planted before rice, it is sometimes recommended that the phosphate meant for application to rice be applied to the green manure instead. Adequate supply of phosphate also promotes greater N fixation.

Biofertilizers

There is a considerable scope for BNF in rice paddies by BGA and/or the *Azolla–Anabaena* association, which may supply up to 25–50 kg N/ha. Inoculation of the paddy-field with BGA can contribute 20–30 kg N/ha. Incorporation of *Azolla* biomass before or during the growth of rice can contribute similar amounts of N along with significant amounts of other nutrients that are present in its biomass. *Azolla* can also accumulate 30–40 kg K_2O/ha from the irrigation water. Information about the multiplication and inoculation with BGA and *Azolla* has been provided in Chapter 7.

Maize (Zea mays L.)

Nutrient requirements

A maize crop producing 9.5 tonnes of grain per hectare under North American conditions can remove the following amounts of nutrients through grain plus stover (IFA, 1992):

- macronutrients (kg/ha): N 191, P_2O_5 89, K_2O 235, MgO 73, CaO 57 and S 21;
- micronutrients (g/ha): Fe 2 130, Zn 380, Mn 340, B 240, Cu 110, Mo 9 and also 81 kg Cl.

Macronutrients

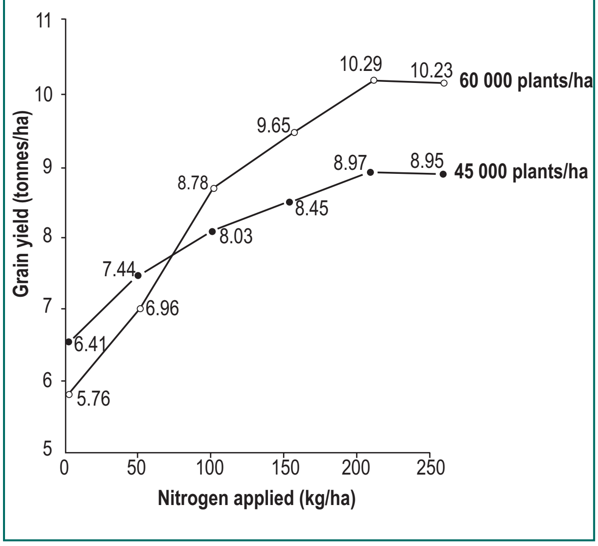
High yield in maize is closely associated with N application, but only where other inputs and management practices are optimal. N interacts positively with plant population, earliness of sowing, variety, weed control and moisture supply. Figure 43 shows an example of the mutual benefit from N fertilizer and enhanced plant population. However, neither higher plant population nor high levels of N alone will improve yields where a third factor is limiting. Where moisture supply is inadequate or uncertain, optimal levels of fertilizer as well as plant population will be below those required for top yields. Fertilizer can improve the utilization of soil water by increasing rooting depth. However, the best returns from N fertilizer are only obtained where the water supply, either natural or supplemented by irrigation, is adequate for full crop growth. Under good growing conditions, a yield response of 30 kg grain/kg N can be obtained.

Maize takes up N slowly in the early stages of growth. However, the rate of uptake increases rapidly to a maximum before and after tasseling, when it can exceed 4 kg N/ha/day. N fertilizer application is best scheduled in accordance with this pattern of uptake in order to avoid serious losses by volatilization or leaching and to ensure that N levels are high in the soil when the crop demand is also high. An application to the seedbed followed by a side-dressing when the crop is knee high, or for very high application rates two top-dressings (the second at tasseling) are usually recommended. The N application rates for rainfed maize are about half of those for the irrigated crop.

Fertilizer requirement in relation to yield level can be calculated directly from crop uptake of N only in specific regions because of the variations in soil N supply and the rather unpredictable efficiency of fertilizer N by the crop. However, N fertilizer requirement may be about 50 kg/ha with unimproved

FIGURE 43

Effect of N fertilizer on maize in relation to plant population



Source: Gros, 1967.

varieties under uncertain rainfall, rising with yield potential to 250–300 kg N/ha where yields of 12 tonnes/ha or more can be expected. Local recommendations on amounts of N should, as always, be based on local experimentation under the prevailing growing conditions. For irrigated HYVs of maize such as hybrids/composites in India, the general recommendation is to apply 60–80 kg N/ha to early-maturing varieties, 80–100 kg N/ha to medium-duration varieties, and 90–150 kg N/ha to late-maturing varieties.

Adequate P is very important for maize as the crop cannot readily take up soil P in the large amounts needed for optimal growth and high yield. Best results from N and other inputs will not be obtained without adequate P, which should be applied mainly in water-soluble form. Rates of P application should be varied according to soil test for available P and in relation to yield potential. These can be in the range of 30–100 kg P_2O_5/ha. Phosphate application in the highly successful maize production region of Illinois, the United State of America, is based on soil tests and crop removals with the twin objectives of building up the soil P level up to the optimum and replacing the P removed by maize at harvest (Table 33).

K is taken up in large quantities by maize but only a small proportion of total uptake is removed with the grain. While maize can obtain appreciable amounts of soil K, it is important to ensure that the overall supply is sufficient for high yields. Use of K fertilizer is especially important where high rates of N fertilizer are used and high yields expected. Recommended rates of K application are in the range of 30–100 kg K_2O/ha. Where the soils are supplied adequately with K, its application is advocated on the basis of soil analysis and yield potential.

In the intensive maize–wheat annual rotation, fertilizer recommendations in subtropical India suggest that the application of P and K to maize can be omitted where the preceding wheat crop has been regularly fertilized with these nutrients or 12–15 tonnes FYM/ha is applied to maize. Organic manures should be applied 3–4 weeks before planting maize. These can be surface broadcast followed by incorporation in the soil.

Both P and K are most effective where applied as a basal dressing before or at the time of planting through a seed-cum-fertilizer drill. Where suitable equipment is available, sideband application, together with a moderate rate of N will improve effectiveness on many soils. Where mechanical equipment for fertilizer application is not available, the fertilizer can be dropped in open furrows and covered with soil before planting.

Micronutrients

Maize can suffer from a number of micronutrient deficiencies. However, Zn deficiency is perhaps the most widespread problem. The problem is mostly on alkaline calcareous soils and soils with a low organic matter content. Zn deficiencies may be intensified by a high level of P supply from the soil and/or fertilizer. Local experience combined with soil and plant analysis can be used as a basis for Zn application. One example of a recommendation from India is to add 25 kg zinc sulphate (21 percent Zn) mixed with 25 kg soil along the row, followed by hoeing and irrigation. Where Zn deficiency symptoms are seen in the standing crop, foliar spray can be given at a per-hectare rate of 3 kg zinc sulphate + 1.5 kg of lime in 500 litres of water.

GRAIN LEGUMES

This section covers two important pulse crops. Major oil-bearing grain legumes, such as groundnut and soybean, are covered in the section on oil crops.

Chickpea (Cicer arietinum L.)

Chickpea is an important grain legume of the arid and semi-arid regions, where it is grown with or without irrigation. The grain contains about 20 percent protein and forms an essential part of human diet in many countries.

Nutrient requirements

A crop producing 1.5 tonnes of grain has been reported to remove the following amounts of major nutrients and micronutrients through total dry matter (Aulakh, 1985):

- macronutrients (kg/ha): N 91, P_2O_5 14, K_2O 60, MgO 18, CaO 39 and S 9;
- micronutrients (g/ha): Fe 1 302, Zn 57, Mn 105 and Cu 17.

A large part of the N is presumably derived from BNF.

Rhizobium inoculation

Being a legume, chickpea can benefit from BNF in association with *Rhizobium*. Therefore, inoculation with *Rhizobium* is often recommended to augment N supply by the soil. The benefit resulting from inoculation is broadly equivalent to the application of 20–25 kg N/ha. Details of the procedure for inoculation have been provided in Chapter 7.

Macronutrients

Even where the soil or the seed is treated with *Rhizobium* biofertilizer, an N application is necessary. This serves as a starter dose and meets the N needs of the crop until the N-fixation system becomes operational. For this purpose, 15–20 kg N/ha is generally recommended. In addition to N, application of 40–50 kg P_2O_5/ha is also recommended. The entire amount of N and P_2O_5 is normally given before planting. There is a strong positive interaction between the availability of moisture and nutrients. The benefits of supplying irrigation increase with increased nutrient application. In S-deficient soils, application of 20–30 kg S/ha through any of the conventional sulphate sources results in a significant increase in grain yields.

Micronutrients

In neutral to alkaline soils (where chickpea is usually grown), Zn and Fe deficiencies can be encountered. To correct Zn deficiency, soil application of zinc sulphate at a rate of 25 kg /ha is suggested under irrigated conditions. Fe deficiency can be corrected by providing foliar sprays with 2-percent ferrous sulphate solutions.

In B-deficient soils, application of borax can increase the yield by an average of 350 kg grain/ha.

Pigeon pea [Cajanus cajan (L). Millsp.]

Pigeon pea is an important grain legume crop. It is perennial in habit but often cultivated as an annual crop. The grain contains about 22 percent protein and forms an essential part of human diet in many areas.

Nutrient requirements

A crop producing 1.2 tonnes of grain has been reported as removing the following amounts of major nutrients and micronutrients through total dry matter (Aulakh, 1985):

- macronutrients (kg/ha): N 85, P_2O_5 18, K_2O 75, MgO 25, CaO 32 and S 9;
- micronutrients (g/ha): Fe 1 440, Zn 38, Mn 128 and Cu 31.

A significant part of this is presumably provided by BNF.

Rhizobium inoculation

Like other legumes, pigeon pea can benefit from BNF in association with *Rhizobium*. Inoculation with *Rhizobium* culture is generally recommended in order to augment soil N supply. The inoculation might result in benefits to the extent of 20–25 kg N/ha. Details of the procedure for inoculation have been provided in Chapter 7.

Macronutrients

Treatment of the soil or seed with *Rhizobium* biofertilizer, application of starter N dose of 15–20 kg N/ha, and 40–50 kg P_2O_5/ha are recommended. Often, for simplicity, the application of 100 kg DAP/ha is suggested, which delivers 18 kg N and 46 kg P_2O_5. The entire amount is normally given before planting. The need for K depends on the soil K status and yield potential of the cultivar. In S-deficient soils, application of 20–30 kg S/ha through any of the conventional sulphate sources results in a 10–15-percent grain yield increase.

Micronutrients

Deficiencies of B and Zn have been widely encountered in pigeon pea. These deficiencies can be corrected by the application of suitable carriers as per local recommendations. As an example, 5 kg Zn/ha can be applied to the soil through zinc sulphate.

OIL CROPS

Groundnut/peanut (Arachis hypogaea L.)

Groundnut, a legume, is major cash crop in India, China and the United States of America. It is also a traditional low-input crop grown in West Africa by smallholders. Its kernels contain an average of 25 percent protein and 48 percent oil. The kernels are used mostly as food in roasted or processed form by humans and also as a source of edible oil. It is well adapted to conditions ranging from semi-arid to semi-humid. The crop grows well on coarse-textured soils, which facilitate the development and growth of pods. After the oil has been extracted, the residue known as groundnut cake serves as an animal feed supplement and sometimes also as an organic manure.

Nutrient requirements

Nutrient removal by a crop producing 3 tonnes pods/ha in the United States of America was reported to be 192 kg N, 48 kg P_2O_5, 80 kg K_2O and 79 kg MgO (IFA, 1992). Nutrient removal per tonne of economic produce under north Indian conditions was of the following order (Aulakh, 1985):

- macronutrients (kg): N 58.1, P_2O_5 19.6, K_2O 30.1, Mg 13.3, Ca 20.5 and S 7.9;
- micronutrients (g): Fe 2 284, Zn 109, Mn 93 and Cu 36.

Rhizobium inoculation

Inoculation with *Rhizobium* culture is usually recommended, particularly where the crop has been introduced recently or has not been grown for several years, or where the native *Rhizobium* population is inadequate and/or ineffective. The groundnut–*Rhizobium* symbiosis can fix about 110–150 kg N/ha. Details of the procedure for inoculation have been provided in Chapter 7.

Macronutrients

Most of the N requirement of a groundnut crop is provided through BNF. Unless soil fertility is high, or organic manure has been applied, a starter dressing of 20–30 kg N/ha is needed to feed the crop until the nodule bacteria are fully established.

Groundnut needs P application for optimal yield and also for the optimal development of nodules in which BNF takes place. Phosphate requirements are normally in the range of 40–70 kg P_2O_5/ha. Generally, an S-containing fertilizer such as SSP is preferred as the source of P because it also provides 12 percent S and 19 percent Ca, both of which are very important for the development of pods and synthesis of oil. The K requirement of groundnut can generally be supplied by soil reserves, residues from previous crops and organic manure. However, potash application is needed on K deficient soils or for high yields under irrigated conditions. Recommendations range from 20 to 50 kg K_2O/ha. Fertilizers can often be sideband placed to advantage.

The nutrition of groundnut requires attention and action beyond supplying just N, P and K. The crop frequently requires supplementary applications of S and Ca. It can also suffer from Mg deficiency in acid leached soils. The S requirement depends on the S input through rainfall and whether or not previous crops have received S-containing fertilizers. S needs can be met by using AS, SSP, ASP, etc. Sources such as gypsum, pyrites and even SPM discharged by sugar factories based on sugar cane can also be used.

Groundnut is unusual in showing Ca deficiency. This can usually be overcome by liming the soil to pH 6.0. In some cases, it is necessary to apply additional Ca in the form of gypsum at the flowering stage. Foliar spray of a soluble Ca salt can also be effective. Ca deficiency can be accentuated by the use of excess K, so that an adequate Ca supply is particularly important where a large K application is made. In many groundnut-growing areas, application of 300–500 kg gypsum/ha is recommended for application at or before flowering. Sandy soils or acid soils may be deficient in Mg, which can be supplied by liming with dolomite. However, excess Mg has the same effect on Ca availability as excess K and, therefore, should be avoided.

Micronutrients

Depending on soil conditions, groundnuts are known to suffer from deficiencies of Mn, B, Fe and Mo. B deficiency, which causes internal damage to the kernels, may also occur on sandy soils, especially in dry conditions. It can be controlled by soil or foliar application of 5 kg borax/ha or two foliar sprays of 0.1-percent borax solution. Mn deficiency is usually attributable to overliming and is controllable by a manganese sulphate spray. Mo deficiency leads to reduced N fixation. As the Mo requirement is very small, it can be supplied as a seed treatment through sodium or ammonium molybdate at the rate of 0.5–1 kg/ha. Iron chlorosis is often observed where groundnut is grown in alkaline calcareous soils. This can be corrected by spraying a solution of 0.5–1-percent ferrous sulphate with 0.1-percent citric acid at 8–10 day intervals. Cultivars that are efficient users of Fe and tolerant of Fe deficiency should be preferred where such seeds are available.

Soybean [Glycine max (L.) Merr]

Soybean is a very energy-rich grain legume containing 40 percent protein and 19 percent oil in the seeds. The crop is adapted to a wide range of climate conditions. The highest soybean yields are produced in near neutral soils but good yields can be obtained also in limed acid soils. Under good growing conditions with adequate N fixation, grain yields of 3–4 tonnes/ha can be obtained.

Nutrient requirements

Total nutrient uptake by the plants per tonne of grain production can be taken as follows (IFA, 1992):

- macronutrients (kg): N 146, P_2O_5 25, K_2O 53, MgO 22, CaO 28 and S 5;
- micronutrients (g): Fe 476, Zn 104, Mn 123, Cu 41, B 55 and Mo 13.

Under conditions favourable for N fixation, a significant part of the N uptake can be derived from BNF.

Rhizobium inoculation

Inoculation with *Rhizobium japonicum* (now known as *Bradyrhizobium japonicum*) culture is often recommended particularly where the crop has been introduced recently or the native *Rhizobium* population is inadequate and ineffective. Under good conditions, the soybean crop will fix 100 kg N/ha or more. Details of the procedure for inoculation have been provided in Chapter 7.

Macronutrients

N fixation can meet a large part of the N requirement of the crop, for which it is usually necessary to treat the seed with bacterial inoculant. The crop may respond up to the application of 100 kg N/ha in the absence of poor BNF. However, in most cases, a starter dose of 20–40 kg N/ha is recommended as it takes some weeks for the nodules to develop and N fixation to start. Large applications of N are needed where N fixation is very low.

Fertilizer P and K requirements of soybean should be based on soil test values. Typical application rates for soils of low nutrient status are 50–70 kg P_2O_5/ha and 60–100 kg K_2O/ha. In the soybean-growing areas of the United States of America, for an expected grain yield of 2.5–2.7 tonnes/ha, the recommended rates of P on low-fertility soils are 40–60 kg P_2O_5/ha, and 100–150 kg K_2O/ha on soils with a low to normal clay content. Application rates are higher at higher yield levels in soils with a high clay content. As an example, for each additional tonne of grain yield, an extra 10–15 kg P_2O_5/ha and 20–30 kg K_2O/ha is recommended.

Soybean responds to the application of Mg and S depending on soil fertility status and crop growth conditions. Significant responses of soybean to S application have been found in many field trials in India. In several cases, it may be advisable to apply phosphate through SSP so that the crop also receives an S application. Where DAP is used, gypsum can be applied to the soil before planting at the rate of 200–250 kg/ha.

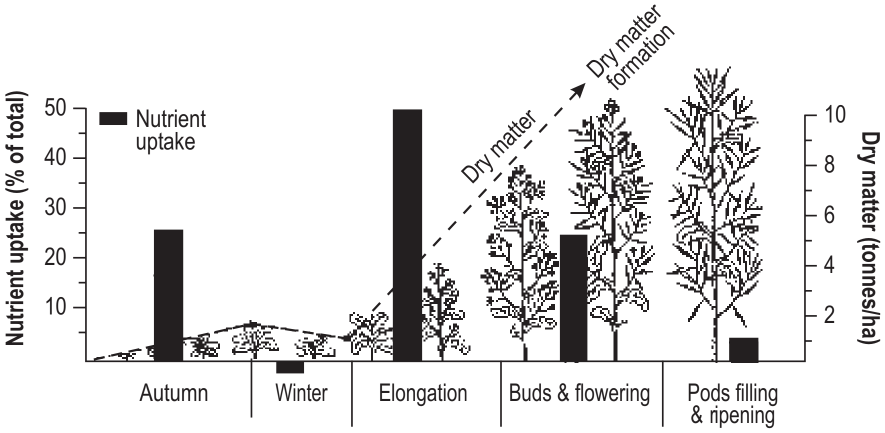
Micronutrients

Depending on soil fertility status and crop growth conditions, responses have been obtained to the application of Zn and Mn. Application of 5 kg Zn /ha on coarse-textured soils and 10 kg Zn /ha on clay soils can remedy Zn deficiency. On Mn-deficient soils, the application of manganese sulphate at a rate of 15 kg/ha to the soils or 1.5 kg through foliar spray increases yield.

Oilseed rape (Brassica napus L.)

Among major oil crops, oilseed rape (canola) is of increasing importance. The oil extracted from the seeds containing 40 percent oil is used for salad oil, as a cooking medium and for fuel. The residues referred to as oilseed cake are protein-rich animal feed. In many parts of South Asia (including India) rapeseed mustard is an important winter-season crop that is grown either alone or as a secondary intercrop in wheat fields. The term rapeseed is a group name referring to various species of Brassica such as *B. juncea, B. campestris* and for rocket salad or *Eruca sativa* but not to *B. napus.* With new varieties of winter rape, including hybrids, high seed yields of 4–5 tonnes/ha are attainable compared with average yields of 3–3.5 tonnes/ha in Europe.

FIGURE 44
Nutrient uptake and growth of winter oilseed rape in different stages



Source: Finck, 1992.

High yields are normally obtained on deep fertile topsoil without a compact layer to facilitate root growth, and a porous crumb structure of the uppermost soil layer for rapid germination of the small seed. This is assisted by a neutral soil reaction and sufficient organic matter for optimal biological activity.

Nutrient requirements

Oilseed rape needs an abundant and timely nutrient supply for good growth and high seed yield (Figure 44). The total nutrients absorbed by a crop producing 4.5 tonnes of seed per hectare are of the order (in kilograms): N 300–350, P_2O_5 120–140, K_2O 300–400, Mg 30–50 and S 80–100. The seeds contain the majority of nutrients except for K, which remains mainly in the straw. Out of the total nutrient uptake, about 20 percent takes place before winter and 50 percent in spring before flowering. In subtropical north India, the total nutrient removal per tonne of seed production by mustard was of the following order (Aulakh, 1985):

- macronutrients (kg): N 32.8, P_2O_5 16.4, K_2O 41.8, Mg 8.7, Ca 42.0 and S 17.3;
- micronutrients (g): Fe 1 123, Zn 100, Mn 95 and Cu 17.

Macronutrients

The N requirements are higher than the N removal figure of 30–35 kg N per tonne of seed. About 30–40 kg N/ha is sufficient for fertilization in autumn. Oilseed rape prefers nitrate N. However, ammonium nitrate is also a good source of N. N solutions and urea can be used except for the very early dose in spring. For the crop in the main growing season, about 250–280 kg/ha N are required from soil and fertilizer. The recommended N rates for seed yield of about 4 tonnes/ha are:

- a first application of 80–100 kg N/ha early in spring on soils that can supply about 40 kg N/ha;
- a second application of 60–80 kg N/ha at the start of elongation;
- a third application of 25 kg N/ha at the beginning of flowering for very high yields.

Correspondingly less N is required for lower yield levels. Oilseed rape tends to leave large amounts of N in the soil after harvest (both as nitrate and as crop residues). These may amount to more than 100 kg/ha N. With good N management, it is possible to keep the mineral N residue below 50 kg N/ha, which is tolerable from a pollution point of view, or to utilize the residual amount by the following crop.

In semi-tropical north India, the irrigated crop can respond to 240 kg N/ha on coarse-textured soils that are low in organic matter. Under dryland conditions, 30–50 kg N/ha is usually optimal. Application of N through AS or of P through SSP is advantageous in S-deficient soils. Response to P is determined by soil P status, moisture availability and yield level. As a general guideline, N and P_2O_5 are recommended in a ratio of 2:1.

The supply of major nutrients should be ample during the growing season, even during short periods of stress caused by dryness or cold. Application should be made at sowing, but a split application with part applied in spring is needed on light soils where losses may occur in winter. The amounts of P and K required depend on the nutrient removal and soil nutrient supply. For a high yield goal of 4.5 tonnes of seeds per hectare on a soil with an optimal nutrient range, the following application rates are suggested (in terms of kilograms per hectare): 80–100 P_2O_5, and 150–200 K_2O. On slightly deficient soils, the amount should be about 30 percent higher, and on soils in the sufficiency range about 50 percent less.

For a yield goal of 4.5 tonnes of seeds per hectare, on medium-fertility soils, the application of 30 kg Mg/ha is also suggested. Brassicas have the highest requirement of S among field crops. The optimal rate of S to be applied depends on the soil S status, yield potential and the level of N applied. In coarse-textured soils, 20–50 kg S/ha may be needed. Until about 1980, almost no fertilization with S was required in Europe because of the large amounts of S supplied through the atmosphere as a result of industrial pollution. In less industrialized parts of the world this was not so. Since atmospheric additions have fallen, S deficiencies have become widespread and rates of 20–80 kg S/ha are required in order to obtain 0.5 percent S in the young leaves. About 10 kg of S are required per tonne of seed yield. In the case of an acute deficiency, foliar spray with a soluble S fertilizer can be used as a quick remedy.

Micronutrients

Because oilseed rape has a B requirement that is at least five times higher than that of cereals, 0.5 kg B/ha should be applied in combination with other fertilizers on deficient soils. The Mn requirement is high and an application of about 1.5 kg

Mn/ha is recommended in many areas, and foliar spraying is effective. Because of the high soil reaction needed by oilseed rape, Mn availability is lowered and deficiencies frequently limit yields. Although only 10–15 g Mo/ha are required by oilseed rape, some soils do not supply this small amount. The need for Mo fertilizers must be based on diagnostic methods. Zn deficiency can be a problem that can be corrected by the soil application of 10 kg Zn/ha. Where the previous crop in the rotation has received Zn application or 10–15 tonnes of FYM/ha have been used, the application of Zn fertilizer can be omitted.

Sunflower (Helianthus annuus L.)

Sunflower is an important oilseed crop containing 40–50 percent oil in the seeds. Potential seed yields can reach 5 tonnes/ha but average yields are much lower. The roots of sunflower plants can reach down to a depth of 2 m.

Nutrient requirements

The total nutrient uptake by a sunflower crop producing 3.5 tonnes of seed per hectare can be of the following order (IFA, 1992):

- macronutrients (kg): N 131, P_2O_5 87, K_2O 385, MgO 70 and CaO 210;
- micronutrients (g): Fe 732, Zn 348, Mn 412, Cu 59 and B 396

Macronutrients

Sunflower hybrids may need an application of 75–80 kg N/ha under irrigated conditions, but 50–60 kg N/ha is adequate for the rainfed crop. Application of N in three splits is advantageous (50 percent at sowing, 25 percent at buttoning and 25 percent at flowering). Excess N increases the risk of disease and lodging, with a consequent reduction in oil content. Recommended rates of phosphate application are 60–80 kg P_2O_5/ha. In view of the very high removal of potash (particularly where the stalks are also removed), potash application is necessary. It should be based on soil tests and crop removal. The recommended rates of potash application range from 50 to 150 kg K_2O/ha. Application of FYM is commonly recommended.

In view of the high S requirement of the crop, S application is normally suggested, particularly on S-deficient soils. This can also be made by using S-containing sources of N or P. Alternatively, S-free fertilizers can be supplemented with gypsum.

Micronutrients

Sunflower is very sensitive to B deficiency on calcareous or sandy soils and under moisture stress. Therefore, special attention should be paid to B nutrition. B may be applied to the soil either at sowing time (1–2 kg B/ha) or at the ten-leaf stage as a foliar application of 500 g B/ha (0.1-percent B solution).

ROOT AND TUBER CROPS

Potatoes (Solanum tuberosum L.)

Nutrition of the potato crop is characterized by its shallow rooting habit and rapid growth rate. Therefore, high yields necessitate an adequate supply of nutrients throughout the growth period. Potato grows best on slightly to moderately acid soils although it can grow successfully in soils with a wide pH range.

Nutrient requirements

Nutrient removal data from a number of situations have been summarized by the IFA (1992). In one estimate from the United Kingdom, nutrient removal (in kilograms per hectare) by a crop producing 90 tonnes tubers/ha was: N 306, P_2O_5 93, K_2O 487, MgO 19 and CaO 10. Results from India show that nutrient removal by potato is higher in the hills than in the plains. In the hills of Simla, nutrient removal by a normal crop yielding 36 tonnes tubers/ha was (in kilograms per hectare): N 117, P_2O_5 32, K_2O 224, S 14, Ca 37 and Mg 63. In the plains, where the crop duration is shorter than in the hills, an adequately fertilized crop yielding 34 tonnes tubers/ha removed 135 kg N, 21 kg P_2O_5 and 157 kg K_2O (Grewal and Sharma, 1993).

Macronutrients

N application promotes early development of the foliage and, therefore, of the photosynthetic capacity during the growth period. However, excess N may delay tuber initiation and so reduce yield. The N requirement depends on many factors including soil type and previous cropping. A preceding legume or another crop with high residual effects, or an application of organic manure, can reduce fertilizer N requirements by 40–50 kg/ha. High-yielding, rainfed or irrigated potatoes in temperate regions, with a growing period of 150–170 days, respond to as much as 200–300 kg N/ha. Most recommendations for potatoes in tropical and subtropical areas are in the range of 80–150 kg N/ha. Recommendations for particular regions and conditions depend on the climate, growing season, soil type, cropping system and variety.

Potatoes utilize both ammonium and nitrate N, but show a preference for ammonium, especially in the early stages of growth. Usually, the entire N is applied to the seedbed. However, in high rainfall conditions, a split application may reduce leaching losses. N applications after the start of tuber development may delay crop maturity. In high rainfall areas, sources such as AS and CAN are superior to urea.

Potatoes need a good supply of readily available P because their root system is not extensive and does not readily utilize less available P forms. Water-soluble P is the most efficient source for potatoes. Moreover, many tropical potato-growing soils are acid and immobilize P fertilizer rapidly. Because of the low P-use efficiency of potatoes, P fertilizer applications need to be considerably higher than the 30–50 kg/ha of P_2O_5 taken up by the crop. Therefore, fertilizer recommendations range from 60 to 100 kg/ha P_2O_5 for most tropical areas. In some temperate regions, the P requirement can be in the range of 100 to 300 kg/ha P_2O_5 depending on soil P status. The applied P is used more efficiently by potatoes where P is sideband placed, especially at low or moderate P application rates.

K plays a major role in starch production by the potato crop. Potato plants well supplied with K are found to withstand frost better than low K plants. Fertilizer K requirement depends on soil type and organic manure application. Irrigation can improve the availability of soil K, and there can be varietal differences in susceptibility to K deficiency. Potash recommendations range from 60 to 300 kg K_2O/ha according to growth conditions and yield level. However, in most developing countries, they are between 60 and 150 kg K_2O/ha. Mg deficiency can occur on leached, sandy soils and may be intensified by large K fertilizer applications. It can be controlled by Mg applied in amendments such as dolomite or by Mg-containing fertilizer materials.

The source of K influences tuber quality as potatoes are sensitive to excess chloride, particularly where tubers are meant for further processing into crisps and other snacks. Hence, application of K through potassium sulphate is usually preferred to potassium chloride. Therefore, potassium sulphate can be recommended where the value of greater starch production exceeds the higher cost of SOP compared with MOP. Potato quality is also influenced by nutritional imbalances. Excess N can reduce tuber dry matter and cooking quality, while K deficiency or excess chloride can cause tuber blackening.

Micronutrients

Soil application or foliar sprays are the widely used methods for supplying micronutrients. The micronutrient needs of potato can also be met simply by soaking the seed tubers in nutrient solutions. The non-dormant seed tubers are soaked in 0.05-percent micronutrient salt solutions for three hours. Dipping seed tubers in 2-percent zinc oxide suspension is also effective for meeting the Zn needs of the crop (Grewal and Sharma, 1993). The high seed rate of potato makes it possible to supply the micronutrient needs of the crop through soaking. The deficiencies of Cu and Mn are controllable by soil or foliar application. The storage life of potatoes can be reduced where there is a B deficiency. Potato cultivars can differ markedly with regard to their sensitivity to micronutrient deficiencies.

Organic manures

Bulky organic manures and green manures have an important place in the nutrient management of potato. They add nutrients and also improve the physical environment for better plant and tuber growth. In spite of their low nutrient content, they help in fertilizer economy. The tuber yields obtained with the combined use of organic manures and fertilizers are higher than those with the use of fertilizers or organic manures alone. Thus, the combined use of organic and mineral sources of nutrients is essential for sustaining high levels of potato production.

Sweet potato (Ipomoea batatas Lam.)

Sweet potato, a perennial root crop, is used for food, animal feed and in industrial materials. China accounts for 80 percent of world production.

Nutrient requirements

Nutrient removal by a crop producing 14 tonnes of biomass per hectare (10 tonnes of tubers and 4 tonnes of leaves) has been estimated at (in kilograms per hectare): N 51.6, P_2O_5 17.2, K_2O 71.0, MgO 6.1, CaO 6.3 and Fe 0.8 (IFA, 1992).

Macronutrients

On most soils, N application increases tuber yield. However, excess N can stimulate foliage production at the expense of tubers and may also lead to tuber cracking. The full benefit from N application is only obtained where there is also sufficient K. It is usual to recommend about 50 kg N/ha, but less on soils well supplied with N. Because the crop removes more K than P, fertilizer K has a greater effect on yield than does P. Under average conditions, about 50 kg P_2O_5/ha should be applied, but this needs to be increased to 70–90 kg P_2O_5/ha on soils with a low P status. The crop needs a good supply of K and an N:K_2O ratio of from 1:1.5 to 1:2. A common recommendation is to apply 80–120 kg K_2O/ha. Potassium chloride can depress root dry-matter content. Where this is the case, the use of potassium sulphate or a mixture of the two sources is recommended. Sweet potatoes can suffer from Mg and S deficiencies, hence their inclusion in the fertilizer schedule may be necessary.

Micronutrients

Sweet potatoes can also suffer from B deficiency, hence corrective control measures may be necessary. Soil application rates range from 9 to 26 kg borax/ha. For foliar application, the suggested rate is 5–15 kg Solubor/ha at a maximum concentration of 2.5–5.0 percent (Shorrocks, 1984).

Cassava (Manihot esculenta Crantz)

Cassava is an important tuber crop of the tropics. It is normally grown at low levels of fertility. Seventy percent of the world's cassava production is used for food either directly or in processed form. Cassava plants have the ability to withstand drought conditions. This is because of their inbuilt mechanism to shed their leaves under adverse moisture conditions. Where raised on natural soil fertility, yields may be very low, but the crop responds well to fertilizer application and to a good moisture regime. While average tuber yields are often 10–15 tonnes/ha, modern varieties grown under good management can yield more than 50 tonnes/ha.

Nutrient requirements

Cassava removes large amounts of nutrients. A crop producing 37 tonnes of fresh tubers per hectare removes the following amounts of nutrients including those contained in tubers (IFA, 1992):

- macronutrients (kg/ha): N 198, P_2O_5 70, K_2O 220, MgO 47, CaO 143 and S 19;
- micronutrients (g/ha): Fe 900 (tubers only), Zn 660, Mn 1 090, B 200 and Cu 80.

Macronutrients

Cassava responds well to fertilizer N with an expected yield increase of 50 kg of tubers or more per kilogram of N applied. With insufficient N, individual tubers are thin and contain less starch. However, excess N may result in an excess of vegetative growth at the expense of tuber yield. A common recommendation is to use 40–80 kg N/ha depending on circumstances. On low-fertility soils, up to 120 kg N/ha can be applied where other growing conditions are favourable. The total N to be applied may be split between a basal application and a top-dressing.

Many soils on which cassava is grown are poorly supplied with P, and the crop has consistently shown considerable benefit from P fertilizer, even though cassava makes better use of soil P than do potatoes. Under most conditions, 40–80 kg P_2O_5/ha is suggested.

A good supply of K is essential for cassava, giving a benefit of up to 100 kg of tubers per kilogram of K_2O and helping to offset the very large removal of K in the tubers at high yield. K increases yield primarily by increasing tuber size. K-deficient plants can contain toxic levels of hydrocyanic acid (HCN) in the tubers. On soils of moderate K status, 100–130 kg K_2O/ha is recommended, with adjustments for different soil K levels. The optimal timing of K application depends on the K status of the soil, which also determines the amount of K to be applied. Generally, K application in two equal splits (50 percent as basal and 50 percent two months after planting) gives best results in terms of starch and dry-matter content. In general, an N:K_2O ratio of 1:1 is suggested.

Micronutrients

Deficiencies of Zn, Mo and B can occur in soils under cassava. With optimal NPK application, soil application of 12.5 kg of zinc sulphate increased tuber yield by 4.0 tonnes/ha; 1.0 kg of ammonium molybdate raised it by 2.8 tonnes/ha; and 10 kg of borax increased tuber yield by 3.1 tonnes/ha. Zn deficiency can be controlled by the application of zinc sulphate at a rate of 5–10 kg/ha at planting or by incorporating zinc oxide before planting. Under moderate deficiency, foliar application of 1–2-percent zinc sulphate may be effective, while under alkaline conditions, stake treatment by dipping in 2–5-percent solution of zinc sulphate for 15 minutes is recommended.

Organic manure

Cassava benefits from an integrated application of organic manures and mineral fertilizers, which produce an additive effect. Under tropical conditions in India, the impact of applying 12.5 tonnes FYM/ha on tuber yields was equivalent to that obtained with 100 kg fertilizer N/ha used alone. Neither FYM nor any of the nutrients (N, P or K) applied individually could increase tuber yields by more than 3 tonnes/ha, but the combined use of FYM + NPK through fertilizers produced a yield increase that was four times greater.

Liming of acid soils

Cassava is often grown in acid laterite soils of pH 4.0–4.5. In such soils, liming has a large beneficial effect on the yield and quality of cassava. In Kerala, the main cassava-growing state in India, liming increased the starch content of tubers and decreased their HCN content. The application of calcium carbonate or a combination of calcium carbonate and magnesium carbonate increased tuber yields substantially.

SUGAR CROPS

Sugar cane (Saccharum officinarum L.)

Sugar cane is a tropical grass that is grown primarily for the sugar content in its stems. Grown on a variety of soils, it grows best on well-drained loams and clay loams. It can grow well in soils of pH 5.0–8.0. Under very acid conditions, liming is necessary, especially to avoid Al toxicity. Because sugar cane has a long life cycle (10–24 months after planting), and in many cases successive harvests (ratoons) are taken, its nutrient management is more complex than that of annual crops. The crop benefits considerably from water and nutrient application.

Nutrient requirements

Under Brazilian conditions, the nutrient uptake per tonne of cane yield is as follows (IFA, 1992):

- macronutrients (kg): N 0.8, P_2O_5 0.30, K_2O 1.32, MgO 0.50, CaO 0.42 and S 0.25;
- micronutrients (g): Fe 31, Zn 4.5, Mn 11, Cu 2.0, B 2.0 and Mo 0.01.

Under Indian conditions, a crop yielding 100 tonnes of cane per hectare absorbed 130 kg N, 50 kg P_2O_5 and 175 kg K_2O. Even on a per-unit cane basis, nutrient uptake varies considerably depending on the climate, cultivar and available nutrient status even at comparable yields (Hunsigi, 1993). Sugar-cane trash is particularly rich in K (3 percent K_2O). It is invariably burned in the field to take a ratoon crop.

Macronutrients

N has a marked effect on cane yields, and an application of 250–350 kg/ha is common. In some situations and with some varieties, excess N depresses cane yield. Sugar content of the cane decreases with increasing N supply and the optimal rate is that which maximizes sugar yield (cane yield × sugar concentration). Excess N may also affect juice quality and sugar recovery. Suitable water management in the final stages of growth can minimize depressions in yield and quality at high N rates.

The requirement for N fertilizer varies with yield potential and, particularly in plant cane, with the soil N supply. Plant cane is able to draw on mineralized N in the soil, which can vary from 50–150 kg N/ha. As an approximate guideline, sugar cane requires 1 kg N/tonne of expected yield. For the ratoon crop, the soil N supply is lower and the rule of thumb is to apply 1.5 kg N/tonne of cane. Thus, for example, a plant cane yield of 100 tonnes/ha would require 100 kg N/ha and a ratoon cane yield of 140 tonnes/ha would require 210 kg N/ha. Much more N may be needed in soils that are very low in organic matter and for intensively grown crops. The recommended rates of N for sugar cane in various parts of India range from 100 to 300 kg N/ha for a 12-month crop.

N for plant cane is usually applied in split doses. The first application of 25–50 percent of the total is made in the planting furrow or broadcast a week or two after planting. The second application should be made during the period of rapid growth and nutrient uptake, one to three months after planting. Where labour is available, the total N can be given in three splits, but all within 100 days of planting. The splits can be given at tillering (45–60 days), formative stage (60–75 days) and grand growth stage (75–100 days). Later applications are often less efficient and may reduce sugar content. For the ratoon crops, N should be applied immediately, or within two months after cutting the previous crop.

More specific recommendations for N, P and K should be obtained from local sources and experience. Various systems of foliar diagnosis such as crop growing and DRIS (discussed in Chapter 4) have also been developed. These provide guidance on fertilizer requirements from the analysis of specified leaves or other organs at specified growth stages.

Phosphate stimulates root growth and early tillering and, therefore, should be applied at planting. Placing P in the planting furrow increases the efficiency of P uptake, especially on less fertile soils. However, many soils adsorb P rapidly so that availability of this initial application can be low for the ratoon crop. The ratoon benefits from an application of P immediately after cutting the previous crop. For soils of medium P status, an application of 100–120 kg P_2O_5/ha to the plant crop is frequently recommended, rising to 200 kg P_2O_5/ha on P-deficient soils. For the ratoon crop, 60 kg P_2O_5/ha will usually provide enough P to stimulate regrowth.

Sugar cane needs a good level of K for a number of reasons. The harvested crop removes very large amounts of K and high yields can remove as much as 400 kg K_2O/ha. K fertilizer increases cane and sugar yields in most cases. Adequate K counteracts the adverse effects of high rates of N on cane sugar concentration and juice quality. Typically, K applications are in the range of 80–200 kg K_2O/ha, but more K may be used on high-yielding, irrigated crops and lower rates on soils rich in available K. Potash nutrition can be monitored by soil and plant analysis, and supplementary applications made where plant K concentrations fall below a specified level.

Sugar cane is sensitive to S and Mg deficiencies. In recent years, owing to the dominance of S-free fertilizers and, hence, reduced S input, S deficiency has frequently been encountered in intensively cropped coarse-textured soils. This can be corrected by using S-containing fertilizers to supply N or P. Application of sugar-factory waste (press mud) from the sulphitation process or of adequate

FYM (15–20 tonnes/ha) can also supplement soil S supplies. Mg deficiencies can occur where soil Mg status is low. Conversely, on soils extremely high in Mg, excessive Mg uptake may suppress K uptake and induce a K deficiency.

Micronutrients

Deficiencies of Zn, Cu and Mn and lime-induced iron chlorosis can occur in sugar cane. These can be controlled by application of deficient elements as their sulphate salts or chelates. Iron chlorosis can be corrected by spraying 2.5 kg of ferrous sulphate in 150 litres of water twice at fortnightly intervals. Sugar cane, like rice, reacts favourably to soluble silicates on some soils, which probably also releases soil P. To correct Zn deficiency, soil application of zinc sulphate at a rate of 25 kg/ha can be made on coarse-textured soils.

Sugar beet (Beta vulgaris L.)

Sugar beet is an important source of sugar in many parts of the world as the roots contain 13–20 percent saccharose. It grows best on slightly acid to neutral soils of porous structure. Under very good conditions, beet yields of up to 80 tonnes/ha can be achieved as compared with an average yield of 35 tonnes/ha.

Nutrient requirements

Nutrient uptake by 10 tonnes of beet along with the associated foliage averages 40–50 kg N, 15–20 kg P_2O_5, 45–70 kg K_2O, 12–15 kg MgO and 5 kg S, out of which the beets contain about 50 percent. Where the leaves are incorporated into the soil after harvest, the nutrients thus recycled must be taken into account in estimating the fertilizer requirement of the next crop.

Macronutrients

The maximum nutrient demand by the crop occurs 3–4 months after sowing. Therefore, most of the recommended nutrients should be applied early, before sowing. In Germany, fertilizer recommendations have been developed for various levels of soil nutrient status. The rate of N is determined by the nitrate stored in the profile at the beginning of the season up to a depth of 91 cm. As an example, 200 kg N/ha is required for a yield of 50–60 tonnes of beets. Where the nitrate content of the soil is 70 kg N/ha, the N to be applied is 130 kg N/ha. For other nutrients on a soil of very low nutrient status and at an expected yield of 50 tonnes of beets per hectare, the recommended rates (in kilograms per hectare) are: 200 P_2O_5, 400 K_2O and 100 MgO. Where the soil nutrient status is high, per-hectare rates of 50 kg P_2O_5 and 100 kg K_2O are recommended.

Micronutrients

Deficiencies of B and Mn can occur because sugar beet has a high demand for these micronutrients, especially on soils with pH of more than seven. Where necessary, 1–2 kg/ha B and 6–12 kg/ha Mn should be applied before sowing, or these nutrients may be applied through foliar spray.

FIBRE CROPS

Cotton (Gossypium spp.)

Cotton, the major source of natural fibre, requires a warm growing season. It grows best on well-drained soils with good structure. Very acid soils need to be limed. An adequate moisture supply is essential, especially during flowering and boll development. Satisfactory rainfed crops are grown in many countries. Cotton is also well suited to irrigated conditions, where the highest yields are obtained. Good management, including timely sowing and effective weed and pest control, is necessary for high yields and for best response to fertilizers.

Nutrient requirements

Under Brazilian conditions, a cotton crop (*G. hirsutum*) producing 2.5 tonnes of seed cotton per hectare absorbed the following amounts of nutrients (IFA, 1992).

- macronutrients (kg): N 156, P_2O_5 36, K_2O 151, MgO 40, CaO 168 and S 10;
- micronutrients (g): Fe 2 960, Zn 116, Mn 250, Cu 120 and B 320.

Macronutrients

N application increases cotton yield by increasing the number and length of branches, and, therefore, the number of flowers, seed cotton yield and seed index. However, the amount of N to be applied depends very much on local conditions (including water supply). Excess N should be avoided as it may reduce yield and quality by overstimulating vegetative growth and delaying maturity. Recommended rates for rainfed cotton are usually 50–100 kg N/ha while most irrigated crops need 120 kg N/ha or more. In some intensively cropped, irrigated cotton-growing regions, N applications are as high as 300 kg N/ha. Soil and plant-tissue analysis for nitrate can be used to monitor the N status of the crop so that the N to be given as top-dressing can be determined. It is usual to split the N application, part being applied to the seed bed and part as a top-dressing at the start of flowering. Irrigated crops with high yield potential may receive two or three top-dressings.

P increases the yield of seed cotton, weight of seed cotton per boll, number of seeds per boll, oil content in seed, and tends to bring early maturity. P application should be related to soil P status. Recommended rates vary from 30 to 100 kg P_2O_5/ha. Highest rates of P are generally recommended for irrigated hybrids, and lowest rates or no P for rainfed traditional cultivars. At low to moderate yields, cotton can be grown without K application, but it should be applied for higher yields, particularly on low K soils. Recommended rates are similar to those for P at 30–100 kg K_2O/ha. In some parts of the world, P and K deficiencies occur where rapidly growing crops are furrow irrigated. This also leads to a loss of bolls in a syndrome known as “premature senescence”.

Cotton is subject to a number of other nutritional problems. Mg deficiency can occur on acid sandy soils. This can be avoided by liming with dolomitic materials. Leaf reddening is sometimes attributed to Mg deficiency. This can be corrected by spraying a solution of 5-percent magnesium sulphate 50 and 80 days after sowing. S deficiency occurs fairly widely in North and South America and in Africa. As little as 10 kg S/ha is required to overcome it, for which any soluble S fertilizer or gypsum can be used.

Micronutrients

B deficiency on cotton has been reported in a number of countries. Fe and Zn deficiencies also occur. All are controllable by well-proven foliar or soil applications. Zn deficiency can be corrected by soil application of zinc sulphate at a rate of 25 kg/ha in coarse-textured soils or by giving three sprays of 0.5-percent zinc sulphate solution during 45 days growth. B deficiency can be corrected by spraying 0.1–0.15-percent B on the leaves at 60 and 90 days.

Jute (Corchorus olitorius L., Corchorus capsularis L.)

Jute is an important fibre crop in which the fibre is extracted from the stem. Of the two main types of jute, *Corchorus olitorius* L. is known as tossa jute while *Corchorus capsularis* L. is referred to as white jute. Jute prefers slightly acidic alluvial soils. Much of the world's jute production is in Bangladesh and India. Improved varieties are capable of yielding 3–4 tonnes of dry fibre per hectare, which is equivalent to 40–50 tonnes/ha of green matter.

Nutrient requirements

On the basis of nutrient uptake per unit of dry-fibre production, white jute has a 40-percent higher nutrient requirement than does tossa jute. Thus, tossa jute is a more efficient species for fibre production. This may be due in part to its deeper and more penetrating root system. Total nutrient uptake per tonne of dry-fibre production, by the two species of jute is as follows (Mandal and Pal, 1993):

- *C. olitorius* (macronutrients, kg): N 35.2, P_2O_5 20.3, K_2O 63.2, CaO 55.6 and MgO 13.3;
- *C. olitorius* (micronutrients, g): Fe 368, Mn 119, Zn 139 and Cu 18;
- *C. capsularis* (macronutrients, kg): N 42.0, P_2O_5 18.5, K_2O 88.5, CaO 60.0 and MgO 24.5;
- *C. capsularis* (micronutrients, g): Fe 784, Mn 251, Zn 214 and Cu 19.5.

An interesting feature of the jute plant from the nutrient management point of view is that a substantial amount of the nutrients absorbed are returned to the soil with leaf fall before harvest. In the case of tossa jute, the percentage of nutrients absorbed that are returned through leaf fall are: N 42, P 19, K 18, Ca 26 and Mg 21.

Macronutrients

The common per-hectare rates of fertilizer application to jute are: 30–45 kg N, 10–20 kg P_2O_5 and 10–20 kg K_2O/. In general, liming of acid soils and the application of 10 tonnes FYM/ha is recommended. Well-decomposed FYM is to be added 2–3 weeks before sowing. In K-deficient areas, K application increases yield and also reduces the incidence of root and stem rot. The Ca requirement in acid soils can be met from liming. In Mg-deficient areas, magnesium oxide can be applied at the level of 40 kg/ha either through dolomitic limestone or through magnesium sulphate. Where noticed, S deficiency can be corrected through the application of common S-containing N and P fertilizers.

Micronutrients

Positive results have been obtained in some cases from the application of B, Mn and Mo. However, micronutrient application should be based on soil nutrient status and local experience.

PASTURES

Permanent pasture and meadows

Areas used for grazing domestic animals cover large parts of the land surface, ranging from sparsely covered wastelands to very intensively managed pastures and meadows. Therefore, plant yields range from less than 1 tonne/ha to more than 15 tonnes/ha of dry matter. Grassland vegetation rarely consists of only one kind of grass, but is mostly composed of various grasses, a variety of herbs and often legumes, which supplies nutritious fodder for grazing animals. On some soils, animals may suffer from deficiencies even with abundant fodder. Extensively used grasslands, composed of native species, are limited in potential by low rainfall or adverse temperatures. The principles of grassland nutrition and some aspects of nutrient supply have been discussed in Chapter 7.

Nutrient requirements

Nutrient uptake under various systems of grassland and fodder production is substantial (IFA, 1992):

- ➢ temperate grasslands (permanent grass and sown grass or leys) for a dry-matter yield level of 10 tonnes/ha:
  - macronutrients (kg): N 300, P_2O_5 80, K_2O 300, MgO 34, CaO 84 and S 24,
  - micronutrients (g): Fe 1 000, Zn 400, Mn 1 600 and Cu 80;
- ➢ temperate grasslands (grass/legume swards) for a dry-matter yield of 8 tonnes/ha:
  - macronutrients (kg): N 320, P_2O_5 69, K_2O 240, MgO 33, CaO 189 and S 25,
  - micronutrients (g): Fe 1 500, Zn 260, Mn 880, Cu 80 and Mo 5;
- ➢ tropical grasses for a dry-matter yield of 8 tonnes/ha:
  - macronutrients (kg): N 170, P_2O_5 46, K_2O 240, MgO 34, CaO 28 and S 16,
  - micronutrients (g): Fe 640, Zn 240, Mn 560, Cu 56, B 160 and Mo 2.4.

Nutrient removal is minimal under grazing as considerable quantities of the nutrients absorbed by the plants are returned to the field in dung and urine. Where the fresh or dry biomass is removed for making hay or silage and off-site feeding, nutrient removal is much larger than under grazing and should be replaced.

Macronutrients

Annual N fertilizer application on grassland varies from 0 to about 1 000 kg N/ha but generally ranges from 50 to 350 kg N/ha. Legumes can supply up to 100 kg N/ha to a grass–legume mixture in temperate areas and 200 kg N/ha in tropical areas. The type of N fertilizer used is of minor importance. Applications of N should be made after grazing or cutting and possibly before the rains, especially with urea. Examples for N application in a temperate climate with good growing conditions are:

- pastures: 150–200 kg N/ha, split into portions of 60 + 50 + 40 + 30 kg N/ha;
- meadows: 250–300 kg N/ha, split as 100 + 80 + 60 + 40 kg N/ha (yield 8–10 tonnes/ha of dry matter).

Fertilization with other major nutrients such as P, K and Mg can be based on nutrient removals, which are small from pastures because of recycling but large from meadows where large amounts of nutrients are removed in hay or silage. On soils of high-fertility status, nutrients removed from the field should be replaced. On pastures, nutrient removals with 1 000 litres of milk are 2 kg each of P_2O_5 and K_2O, and 0.2 kg Mg. For intensive pastures, inputs of 20–30 kg/ha each of P_2O_5 and K_2O, and 3 kg/ha of Mg are suggested. On meadows for dry-matter yields of 10 tonnes/ha (12 tonnes of hay), about 100 kg/ha P_2O_5, 300 kg/ha K_2O and 35 kg/ha Mg are adequate. Any kind of P fertilizer can be used. Potash fertilizers should preferably contain some Na in order to meet the needs of animals. S deficiency is being recognized in many areas that do not receive S input through fertilizers or atmospheric pollution.

Micronutrients

Adequate Mo is essential for effective N fixation. Where Mo deficiency is recognized (often in acid soils), Mo should be applied, most conveniently in the form of fertilizers fortified with Mo, e.g. molybdenized SSP (0.02 percent Mo).

Organic fertilizers

Grasslands often receive abundant manure and slurry, but mainly as nutrient sources and less for the supply of organic matter. Single applications of slurry should not exceed 20 m^3/ha on sown pastures. Up to double these amounts are acceptable on meadows and pasture, but grazing should not take place for several weeks after slurry application.

Chapter 9

Economic and policy issues of plant nutrition

There are many complex economic and policy issues related to nutrient management. A detailed discussion of the subject is beyond the scope of this document and readers are referred to the publication on *Fertilizer strategies* (FAO/IFA, 1999). In view of the importance of the subject, some practical aspects are discussed here.

Before farmers can be convinced about applying a purchased input such as mineral or organic fertilizer, they need knowledge about such inputs and their effects on crop yield in both agronomic and economic terms. Once convinced of using fertilizers in principle, they have to make the complex decision on how much and which fertilizer to use. Their decision on whether to use fertilizer on a particular crop is generally based on some form of economic judgement that includes past experience from using such inputs, the cash or credit available, and probable produce prices.

While calculation of the economics of applying fertilizers is relatively straightforward, the economics of using nutrient sources such as animal manure, compost, crop residues, green manure crops and urban wastes is more complex. Critical elements in the calculation of the economics of using these products are their variable nutrient composition, their residual effect and the cost and availability of labour to access, process and apply them. These factors are often overlooked when advocating different nutrient management strategies.

For practical use, all agronomic data on crop responses to nutrients should always be subjected to economic analysis in order to account for differences in input and output prices and to address the basic issue of whether and to what extent fertilizer application will be profitable to the farmer. The discussion here uses mineral fertilizers as an example but the issues are also applicable to the other nutrient sources. Information on the factors that affect the returns from nutrient application is equally valuable in decision-making.

FACTORS AFFECTING DECISION–MAKING

The principal elements of production economics as applied to fertilizer use consist of:

- physical yield response to applied fertilizers, price of fertilizer and crop including transport, handling and marketing costs as also the cost of servicing a loan;
- the individual farmer's decision-making and risk-taking ability.

The following economic and institutional factors have been identified as important in influencing the economics of fertilizer use (FAO/FIAC, 1983):

- ➢ The price relationship between fertilizers and the crops to which they are applied together with the market outlook for these crops, which largely determines the profitability and incentive for using fertilizers.
- ➢ The farmers' financial resources along with the availability and cost of credit, which largely determine whether farmers can afford the needed investment in fertilizers.
- ➢ Conditions of land tenure, which determine the degree of incentive for farmers to use fertilizers.
- ➢ Adequate supplies and distribution facilities in order to ensure that the right types of fertilizers are available to farmers at the right place and right time.

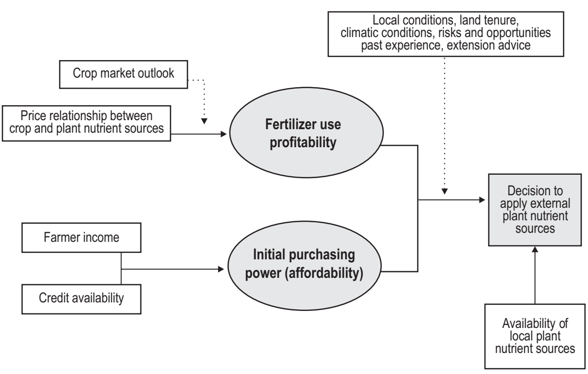
Although the relative importance of these factors varies depending on local and seasonal conditions, they are interdependent to a considerable extent. Each of them can be influenced positively or negatively by the government policies, financing facilities and marketing systems in a country.

Farmers will apply plant nutrients only where their beneficial effects on crop yields are profitable. The decision to apply external plant nutrients on a particular crop will generally be based on economics (price and affordability), but conditioned by the availability of resources and by the production risks involved (Figure 45).

Ideally, farmers' pursuit of higher income through higher yield should be balanced against the need to maintain soil fertility and avoid soil degradation. Most farmers in developing countries have little choice except to face a certain amount of soil fertility depletion each year. Therefore, the profitability of adopting INM should be viewed over a longer term as improvements in soil conditions associated with superior NUE tend to become apparent only after several cropping seasons. Thus, apart from the physical response to the application of plant nutrients, certain economic and institutional factors are also important determinants for decision-making on fertilizer use.

Small-scale farmers in harsh climates (drylands) and with scarce resources are compelled to look for short-term results when applying plant nutrients. Improved access to markets and low-risk production technology coupled with the removal of financial constraints and operational constraints (such as recycling of rainwater) will allow them to adopt plant nutrient

FIGURE 45
An example of the decision-making process used by farmers



Source: FAO, 1998.

management practices that are economically attractive and can support long-term sustainable crop production. It is not easy to have all these favourable conditions simultaneously.

Climate is one of the most difficult factors to take into account in deciding on nutrient additions to crops and pastures. In some developed agricultural areas, account is taken of soil moisture at planting and of the probability of rainfall using data provided by meteorologists. In irrigated areas, the availability of water can usually but not always be predicted.

In many developing agricultural areas, no such information is available and farmers must rely on their own experience and the experience of others. In this situation, the risk is much higher than in developed areas. As shown in Figure 35, the rainfall pattern has a major influence on crop response and, hence, economic returns to nutrient application. In the drought year, no fertilizer should have been applied, while in the year with above average rainfall, even the normal rate of application would have been insufficient for maximum yields. In those developing countries where irrigation facilities are well developed (e.g. India and Pakistan), the element of uncertain water supply is reduced. This allows farmers to invest in nutrients and target high yields. It is in such areas that the so-called green revolution took place and the productivity of irrigated cereals rose many times over in the period 1965–1990.

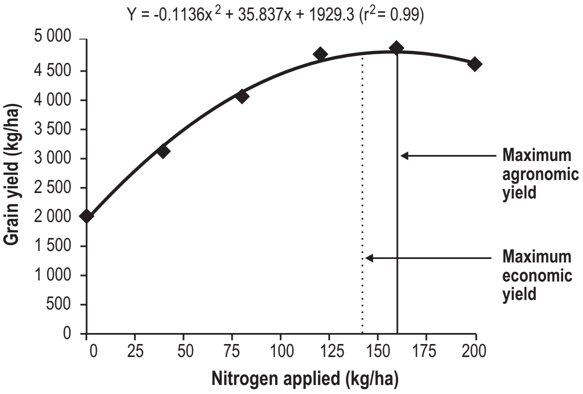
Yield maximization vs profit maximization

The basic requirement of profitable crop production is to produce an agronomic yield that can maximize net returns. Even the highest yield would not be of interest if its production were not cost-effective. Most farmers would like to maximize the net gains from whatever investment they can make in inputs. However, they should realize that top profits are possible only with optimal investment, correct decisions and favourable weather.

Whether a farmer aims for the maximum economic yield or maximum agronomic yield depends on circumstances. A farmer in a poor agricultural area with little or no purchasing power will generally try to produce sufficient food for family needs at the lowest risk. Such farmers are forced to operate at a subsistence level of farming. In these situations, maximum yields are not considered and even maximum economic yields are a distant goal. On the other hand, farmers in a developed area (even within a developing country) with access to cash and/or credit will generally try to maximize their return on invested capital and they are better equipped to take some risk.

The response function to fertilizer use is a basic tool that relates the amount of crop that can be produced in relation to the amount of fertilizer and other farm inputs applied. In other words, there will be a maximum obtainable amount of crop produce for any given amount of fertilizers and other farm inputs used. This is influenced considerably by the soil fertility status and this is why economically optimal rates of nutrient application should generally be based on soil tests and crop removals as discussed in Chapters 4, 6 and 7.

FIGURE 46
Response function of wheat grain yield to added N established in a field experiment



In theory, the determination of the response function should take into account all variables, such as the use of other inputs that influence crop yield. In a response function, crop yield is a function (f) of several factors: $Y = f(X_1, X_2 .... X_n)$, where Y = crop yield, and $(X_1, X_2 ..... X_n)$ = inputs included within the response function as having the major influence on production.

However, normal practice in fertilizer response function studies is to restrict the variable inputs to the rate or level of fertilizer nutrient applied keeping all other factors constant. At the farm level, this can be a limitation as it does not take into account factors such as labour costs and weather fluctuations.

The important information supplied by the response function is the increment of crop yield (grain, tubers or fruits) obtainable from increasing levels of fertilizer application. This information is essential for determining the optimal fertilizer application rate (i.e. the most profitable level of fertilizer use). Such a level is not valid for all time even for a given crop on a given farm. It changes constantly depending on input costs, output price and the rate of crop response per unit of input.

The classical production function normally exhibits stages of increasing, diminishing and negative returns according to the law of diminishing returns whereby, beyond the initial linear range, successive increments of input result in a decreasing rate of response per unit of fertilizer applied. Farmers are interested only in the first and second stages of the response function. Their specific interest depends on whether their main consideration is maximization of profit or the rate of net return (BCR) from the money spent on fertilizer. This attitude is conditioned by the resources available and by their views on risk and uncertainty. Where the response function to a given input is known, as shown in Figure 46, it is possible to compute the economic and agronomic optimal application rates. Using N as an example, the response function is of the form:

$$Y = -0.1136X^2 + 35.837X + 1\,929.3$$

where Y = wheat grain yield valued at US\$0.25/kg, and X = rate of N applied as fertilizer costing US\$0.90/kg N.

In order to calculate the rate of N for maximum agronomic yield, the first derivative of the response function has to be set to zero: $dY/dX = 0 = -0.228X + 35.84$, $X = 157$ kg N/ha (for maximum yield).

The profit-maximizing optimal rate of N is calculated by setting the first derivative of the response function to the price ratio of the fertilizer to the grain price, i.e. (US\$0.90/US\$0.25): $0.228X + 35.84 = 0.90/0.25$; $X = 141$ kg N/ha (for maximum profit).

The yield-maximizing rate of nutrient application (any nutrient) will be somewhat higher than the profit-maximizing rate (157 vs 141). This is because the extra yield from maximum economic to maximum agronomic is uneconomic. Unless a farmer is aiming to win a highest yield competition, the profit-maximizing rate of nutrient application should not be exceeded.

While analysing the economics of fertilizer use, the principal considerations are the production increase attributed to fertilizer (or physical response), and the relationships between the cost of fertilizers and the price of produce. Where the objective of farmers is to obtain the economic optimal value from the use of fertilizer, their concern is to operate within the second stage of the response function where the yield obtained from a unit of fertilizer (the marginal yield) is increasing but at a decreasing rate.

Table 39 presents an example where the application rate of 150 kg N/ha is divided into six increments of 25 kg each. The example in Table 39 can be computed for any monetary unit. As illustrated in this table, each increment up to 125 kg N/ha produced sufficient crop to leave a net profit. As the number of units of N increased, the total crop yield also increased while the marginal yield increase per unit of fertilizer applied (column 5) declined. The marginal return from the fifth increment (from 100 to 125 kg N) was positive. However, the next increment (from 125 to 150 kg N) resulted in a net loss. This was because the 20 kg of grain it produced was not enough to pay for the 25 kg of N used to produce it. Hence, the marginal rate of return for the last increment was not favourable for going beyond 125 kg N/ha. The exact cut-off point would be the last kilogram of N that paid for itself. That would also be the profit-maximizing rate. It can be calculated for any situation.

In simple terms, the yield-maximizing dose (YMD) (close to 150 kg N in Table 39), is always somewhat higher than the profit-maximizing dose (PMD) (close to 125 kg N). The small portion between PMD and YMD consists of a positive but uneconomic response. For farmers in general, the PMD is of interest.

TABLE 39
The economics of incremental crop response to increasing rates of fertilizer application

N added	Yield	Each increment of N		Effect of each increment on yield		Net returns (value - cost)
			Cost	Crop	Value	
(kg/ha)	(kg/ha)	(kg/ha)	(Rs10/kg)	(kg)	(Rs)	(Rs)
0	1 500	0	–	–	–	–
25	2 200	25	250	+700	4 200	+3 950
50	2 750	25	250	+550	3 300	+3 050
75	3 150	25	250	+400	2 400	+2 150
100	3 400	25	250	+250	1 500	+1 250
125	3 550	25	250	+150	900	+650
150	3 570	25	250	+20	120	–130

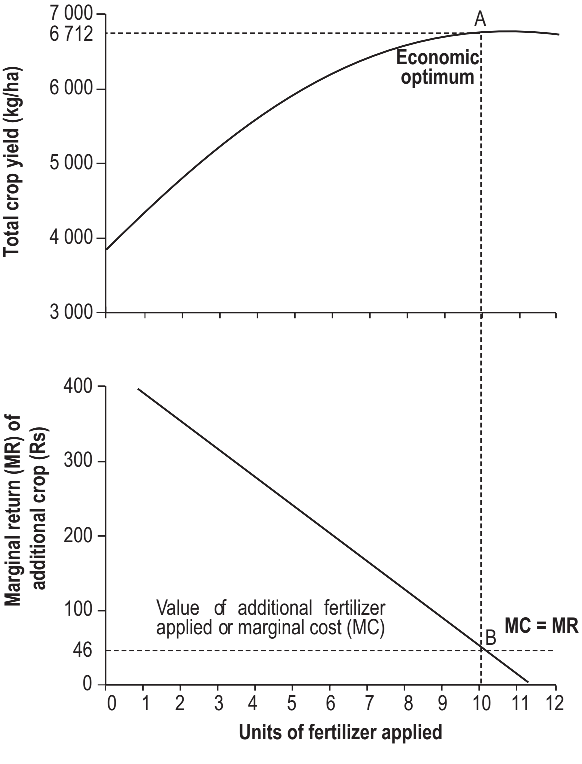
Maximization of net returns or value–cost ratios

A question is sometimes raised as to whether a farmer should aim at maximum net returns from fertilizer use or at the maximum rate of gross returns as indicated by the value–cost ratio (VCR).

The decision by farmers to use fertilizer based on the VCR level depends on their own standard of profitability. However, the general rule is that a VCR of at least 2:1, i.e. a return above the cost of fertilizer treatment of at least 200 percent, is attractive to farmers. However, the absolute net return should also be considered because, at low application rates of fertilizers, the VCR may be very high owing to the small cost of the treatment and the associated high rate of response. However, at low application rates, the net return would also be small and unattractive to farmers. In addition, other factors should also be taken into account. These include the likelihood of the expected yield being obtained, produce storage facilities, an assured market for the crop, and the assured availability of the fertilizers to farmers. This aspect is discussed below.

FIGURE 47

Relationship between crop response and profit



Note: US$1 = Rs 45.3.

Source: FAO/FIAC, 1983.

As the ratio of crop and fertilizer prices changes, the amount of fertilizer applied also needs to change in order to maintain optimal economic returns. The extent of the change depends on the shape of the response curve. This concept of economic optimum based on the rate of marginal return is further illustrated in Figure 47 using data from India. It is important that information on marginal yield and the prices of fertilizer and crop produce be available. Such computations can be made for any situation.

Most farmers, particularly in developing countries, often use less than the recommended fertilizer rates, and do so too in an imbalanced manner. This is because of a number of factors that include: their perception about the role or importance of each nutrient and its unit price; the anticipated yield increase; expected crop prices; cost and availability of fertilizers; level of financial resources and credit availability; land tenure considerations; the degree of risk and uncertainty, and the farmers' ability to bear them. Therefore, it is natural for farmers to be cautious and build in a fair safety margin when deciding the level of fertilizer to apply. Farmers can operate over a wide range of fertilizer application rates and benefit from them right up to the optimal level. In this respect, plant nutrient sources are very different and very flexible compared with other agrochemicals (pesticides and herbicides) that can only be effective where applied at a single critical rate.

Generally, farmers with sufficient resources can use fertilizer rates that are at or near the optimum in terms of economic returns. On the other hand, the rates of fertilizer application of interest to small-scale farmers with limited resources, who are concerned with the economic return on the money they spend on fertilizers, are those on the steeper part of the response curve where the BCRs (discussed below) are higher. However, such farmers will be sacrificing a considerable portion of the achievable yields and profits by operating below the optimal level.

ECONOMICS OF FERTILIZER APPLICATION

The required data sets

For a simple analysis, the minimum data required for economic analysis of fertilizer use consist of: (i) cost of fertilizer; (ii) value of the extra crop produced as a result of using the fertilizer; and (iii) the rate of increase in yield per unit of nutrient applied or the rate of response. For nutrients that leave a residual effect and benefit more than one crop, the cost of nutrient should be distributed among the crops benefited.

For a detailed economic analysis, the data set required is much larger and consists of:

- ➢ cost (expenditure):
  - cost of fertilizer (net),
  - interest on loan taken to buy fertilizer (until it is repaid),
  - transport charges of fertilizer to the village,
  - fertilizer application costs (labour, machinery and energy),
  - harvesting, threshing, winnowing and storage cost of extra crop produced by fertilizer use,
  - cost incurred in storage of produce,
  - cost of transporting the extra produce to the market,
  - direct and indirect marketing cost,
  - adjustment in fertilizer cost for residual benefit credited to next crop;
- ➢ income:
  - sale proceeds from main produce resulting from fertilizer use (grain, fruit, tubers, etc.),
  - sale proceeds from products resulting from fertilizer use (straw, stover, sticks, etc.);
- ➢ gross returns: sum of items under income;
- ➢ net returns: gross returns - cost;

- rate of gross returns: gross returns/cost (VCR);
- rate of net returns: net returns/cost (BCR).

Computation of economics

Apart from calculating the economically optimal nutrient application rates that are associated with maximum net returns, the rate of profitability of fertilizer use can be determined by using either the VCR or the BCR. The VCR is obtained by dividing the value of extra crop produced by the cost of fertilizer or any other nutrient source. The BCR is obtained by dividing the net value of extra crop produced (after deducting fertilizer cost) by the cost of fertilizer. Therefore, the VCR is an indicator of the gross rate of returns, while the BCR indicates the net rate of returns. In a simple way, BCR = VCR - 1.

Economic analysis can also be used to determine the units of crop produce required to pay for one unit of fertilizer nutrient or, alternatively, in a given price regime, the response rate required for a commonly accepted minimum VCR. Where three units of grain are needed to pay for one unit of nutrient, then a response rate of 6 kg of grain per kilogram of nutrient must be obtained for a VCR of 2:1. This also has implications for NUE as an improvement in efficiency will result in a higher VCR from the same investment.

Many fertilizer trials-cum-demonstrations do not permit the calculation of the response curve to the different nutrients owing to the design used. Nevertheless, where the range of treatments is wide enough, the net return and VCR can be determined. The example in Table 40 (based on FAO Fertilizer Programme data) illustrates this.

In the example in Table 40, the lowest N–P_2O_5–K_2O treatment (40–40–40) gave the highest response and highest net return with a high (but not the highest) VCR of 4.3. On the other hand, the highest N–P_2O_5–K_2O treatment (80–80–80) did not give the highest response or economic return. The highest VCR was obtained from the 40–0–0 treatment and its economic return was only slightly less than that from the 40–40–0 treatment. Assuming these results to be economically representative, the 40–40–40 treatment could be recommended for use by the better-off farmers and the 40–0–0 treatment by those with limited resources to purchase fertilizers. The real economically optimal rate is somewhere between the 40–40–40 and 80–80–80 treatments and this should be computed statistically. Depending on the

TABLE 40
Example of net returns and benefit-cost ratio as determined from the results of field trials

Treatment N–P_2O_5–K_2O (kg/ha)	Yield increase (kg/ha)	Increase (%)	Gross return	Cost of fertilizers (US$/ha)	Net return	VCR
Control	3 000	-	-	-	-	-
40–0–0	890	29	122.82	16.80	106	7.3
40–40–0	1 090	36	150.42	30.30	120	5.0
40–40–40	1 455	49	200.79	47.10	154	4.3
80–80–80	910	30	125.58	94.20	31	1.3

soil fertility level, it is possible to indicate that the profit-maximizing rate is either 80–60–60, 80–80–40 or 80–40–60.

Calculating the economics of residual value of nutrients

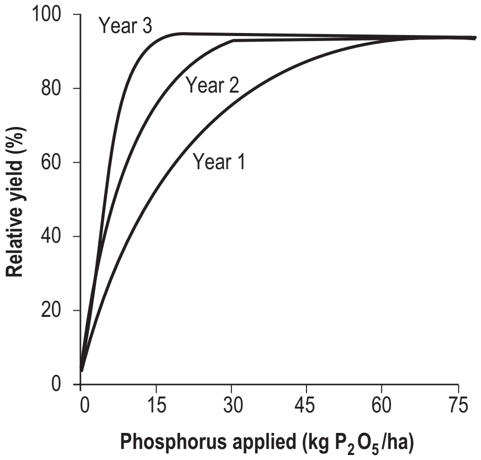
The application of a number of nutrients, particularly P, S, Zn and Cu, benefits more than one crop in succession. P is the best-known example among the major nutrients that leave a residual effect.

Where repeated applications of P are made, the P not used from the first application remains effective in the soil and can contribute to P supply to the following crop. In most cases, the economics of P fertilization in many developing countries continue to be worked out on a single-crop basis. Where a fertilizer trial with a nutrient such as P is conducted with repeated applications made in three successive years, the response curve appears to move to the left (Figure 48). The reason for this is that the residual P from the first-year application is contributing to the P supply in the later years. This implies that as the soil P status improves as a result of repeated applications, lower rates of P application are needed in subsequent years to obtain optimal yields. This allows for the exploitation of accumulated P on a limited scale. Such an increasing P status of soils should be reflected in a good soil test report so that the optimal P application rate can be adjusted. The same principle applies to all nutrients that leave behind a significant residual effect (Zn and Cu on a longer-term basis, and S on a relatively shorter-term basis).

Ideally, the contributions of residual P should be assigned a monetary value, and also an interest could be charged on the money locked in this P. This may not be acceptable in all cases, e.g. where the farmer argues that the freshly applied soluble P is more valuable (more effective) than the less soluble residual P. For practical purposes, it is necessary to know the number of crops that will benefit significantly and the quantum of benefit (response). Where four crops in succession benefit from an initial application and their successive share of the cumulative yield increase (crops 1 to 4) is taken as 100, then the cost of P fertilizer can be apportioned to each crop according to its contribution in the cumulative response.

FIGURE 48

Yield response to P application at a fixed site when P is re-applied in three successive years



The challenge lies distributing the cost of a P application among various crops raised in a sequence that are the potential beneficiaries. Theoretically, if the effect of a P application last four years and the percentage share of each crop in the total yield increase obtained over four years is 50, 30, 15 and 10, then the cost of an initial P application can also be allocated in this proportion for economic analysis on a cropping-system basis. As an example, only 50 percent of the cost of P may be set against the crop receiving it because the remaining 50 percent of yield response is observed in the following three crops. This also helps in modifying the rates of application on builtup soils ultimately reaching P replacement (removal) values.

In one study (Goswami, 1976), the direct and residual response to P was evaluated in several systems of double cropping involving two crops in succession per year in India. Averaged over several field experiments with cereals, out of the total rotational response to P, the direct component was 60 percent and the residual component was 40 percent. Where P was added to the rainy season cereal and the winter crop was raised on residual P, the total rotational response consisted of 57 percent direct and 43 percent residual. Where the same amount of P was applied to the winter crop, the rotational response was made up of 63 percent direct and 37 percent residual. This shows that even in a single-year rotation, dividing the cost of P among the two crops is justified. Such partitions between direct and residual effects should be based on local research.

The effect of taking the residual effect into account in the economics of P fertilization is illustrated in this example using an application of 60 kg P_2O_5/ha to wheat in a wheat–rice cropping sequence:

- response of wheat to P (direct): 500 kg/ha;
- response of rice (residual): 300 kg/ha;
- value of wheat produced: US$66;
- value of rice produced: US$33;
- cost of 60 kg P_2O_5 through DAP: US$20;
- net returns from P use (basis: direct effect only): US$46 (66 - 20);
- net returns from P use (basis: direct and residual effects): US$79 (66 + 33 - 20);
- VCR with direct effect only: 3.3 (66/20);
- VCR with direct and residual effects: 5.0 ((66 + 33)/20).

The economics of P application also improve where the higher response is also for a crop that has a higher market value (e.g. wheat as opposed to millet, or oilseed as opposed to cereal). Thus, a beginning could be made towards economic analysis on a cropping-system basis by allocating only 60 percent cost of P fertilizer to the first (directly fertilized) crop. Otherwise, the returns from P application to the directly fertilized crop would suffer a penalty while the crop feeding on residual P would receive a bonus in terms of P residues. The detailed analysis should include more than one crop that benefits from the residual effect, as discussed below.

Calculating the indirect costs of applying fertilizers

Where fertilizers are applied to soils, many of them affect soil pH and other soil properties. Where acidifying fertilizers are applied that lower soil pH, the acidity produced has to be corrected by the application of liming materials. When the same fertilizers are applied to alkaline soils, the acidifying effect may result in additional benefits, such as increasing the availability of some nutrients (e.g. P and Zn). It is possible to ascribe a value to this effect although not directly but in terms of yield equivalent involved. In principle, this means that fertilizers should be costed not only for the nutrient they supply but also for their positive and negative effects on soil health.

Where AS is used as a source of N, the cost of lime needed to neutralize the acidity produced by the AS should be added to the cost of the AS. Similarly, where SSP is used as a fertilizer on S-deficient soils, its cost should be split between P and S. In the case of crops such as groundnut, where the Ca component of SSP also plays a role in pod formation, the cost of SSP should be split between P, S and Ca, particularly on acid soils. These are the issues that warrant examination where one moves from one-sided to multifaceted economics of nutrient application.

ECONOMICS OF ORGANIC MANURES AND BIOFERTILIZERS

The calculation of the economics of organic manures and biofertilizers is more complex than that of nutrients applied through mineral fertilizers, especially N (which leaves no or only a small residual effect).

Organic manures

Bulky organic manures have a more profound effect on improving soil physical properties than on nutrient supplies. The monetary value of improvement in soil conditions is not easy to estimate. However, the physical and chemical advantages of using organic manures are expected to be reflected in the crop yield increase. Therefore, it is simple to compute the economics of organic manures by treating them in the same manner as fertilizers that give both a direct and a residual benefit. It is easier to cost organic manures on the basis of cost of material plus application cost without splitting the total amount into individual nutrients. A further complication arises in trying to divide the cost of an organic manure among nutrients and organic matter, which primarily affects soil physical properties. The yield increase is expected to reflect the improvement in soil physical conditions as a result of manuring as well.

Green manures

Green manures bring in the organic matter produced as a result of photosynthesis but otherwise recycle the soil nutrients absorbed by them. Leguminous green manures do bring in a net N input. This can be costed in terms of equivalence of fertilizer N (if similar use efficiencies are assumed) or the cost of raising the green manure and the value of extra crop produced can be used for working out the economics. Here again, residual effects should be taken into account.

Biofertilizers

The economics of biofertilizers or microbial inoculants can be calculated either by costing the biologically fixed N in terms of the cost of fertilizer N that produces a similar yield increase, or by deducting the cost of inoculant plus its application cost from the value of extra yield produced. Residual benefit from the N fixed as a result of inoculation is not easy to compute except in terms of the value of extra crop produced.

It is necessary not to lose sight of the many ways in which a farmer can end up with low returns or even run into loss by using fertilizers. Prominent among these are: (i) continuous imbalanced nutrient application; (ii) growing low-yielding crop varieties; (iii) inefficient fertilizer use; and (iv) application of fertilizers without addressing other soil health constraints such as strong acidity or alkalinity. In order to maximize profits from fertilizer use, it is necessary to devote equal attention to factors and inputs other than fertilizers.

POLICIES FOR EFFECTIVE PLANT NUTRITION

Long-term planning and monitoring of the use of plant nutrients needs to aim at reconciling four objectives: (i) agronomic and economic efficiency to maximize agricultural output from available nutrient supplies; (ii) maintenance and enhancement of the production capacity of the natural resource base; (iii) consistency with a country's overall economic goals; and (iv) safeguarding the social security and livelihood-earning capability of the rural populations. Timely consideration of these issues is essential to planning and implementing a consistent and comprehensive policy both in the short term and the long term.

Fertilizer policies need to develop into INM policies so that diverse sources of plant nutrients find their rightful place in meeting the total nutrient needs of a country. Such a policy, besides serving as a tool for minimizing the depletion of soil fertility, would provide for a judicious use of the locally available manurial resources, maintain the soils in good health, ensure good yields on a sustained basis, and minimize the adverse impact of mineral nutrient resources on environment.

Planning

The efficient management of plant nutrients requires adequate involvement and planning in a wide range of areas. These tasks should ideally involve government, cooperatives and the private sector. A focal point for advice and planning on various sources of plant nutrients is essential for the establishment of a well-integrated plant nutrition policy including fertilizer policy. This should be well coordinated with the country's agricultural and food-security policies. An advisory unit with these functions could also provide required inputs for the formulation of a pricing and marketing policy. Such a unit could be made responsible for demand forecasting and identifying linkages with industry, research, extension services and farmers associations.

Assessment of nutrient requirements

An accurate assessment of plant nutrient requirements is the basis for planning the use of local sources of nutrients and for deciding upon domestic production and/or import of fertilizer products and raw materials, including the eventual use of foreign exchange to finance imports. Fertilizer demand projection is an assessment of the plant nutrient volumes that will be required to meet agricultural production targets. As against this potential demand, actual demand refers to the quantities that growers are likely to order. For example, in the case of N, in areas with sizeable acreage under legumes and wetland rice, the contribution of N from appropriate biofertilizers should be taken into account for finalizing total N needs. These should also take into account the nutrients expected to be available from organic resources on a realistic basis. Policies on the effective use of phosphates should include the use of a wide range of materials varying from fully water-soluble fertilizers to effective PRs depending on soil pH, crop duration, availability of local resources and distribution logistics. Similarly, policies concerning potash requirements should take into account the scope for recycling K-rich crop residues, organics and finished fertilizers.

Quality control

The setting up of fertilizer quality standards is an important part of fertilizer policies. Many countries have a fertilizer legislation in place and the machinery to enforce it. Fertilizer legislation deals with product specifications in terms of nutrient contents, inert material, physical properties, weight, packaging and labelling requirements, and the measures to enforce the legislation. Although the scope of fertilizer legislation varies from country to country, it usually has the following features:

- It defines the term “fertilizer” and provides a list of materials that can be labelled and sold as fertilizers. This means that no unlisted material can be labelled or sold as a fertilizer even though technically it may be an excellent fertilizer.
- It lays down the quality standards for the listed fertilizer products and specifies their physical and chemical properties in quantitative terms for maintaining quality. Apart from the nutrient content, specifications concerning the moisture content, particle size and the permissible limits of undesirable constituents are indicated.
- It lays down the packaging and labelling requirements and specifies the information to be provided on the fertilizer bag or any other type of packing.
- It lays down the procedures and regulations for the registration and licensing of the manufacturers, importers, and the distributors, along with the details relating to the mandatory information to be furnished by them to the regulatory authority at prescribed intervals or as and when required, besides identifying the personnel entrusted with the task of enforcing the legislation, their duties and their powers.
- It lays down the procedures for collection of samples, search procedures, disposal of substandard stocks, seizures of stocks, issue of notices in case of legislation violation, and initiation of legal proceedings.
- It specifies detailed standard analytical methods for fertilizer samples for quality checking.

At present, most such legislations are confined to mineral fertilizers. In several countries where quality standards have been or are being developed for organic and biofertilizers, these are not always a part of the legislation. In such situations, quality standards cannot be enforced by law – a situation that INM policies need to remedy.

Labelling

Product labelling is generally specified in the fertilizer legislation of many countries. It is essential to provide correct information about the product to dealers, extension workers and farmers. Labelling also permits the enforcement of fertilizer legislation. In several countries, detailed directives are given to manufactures as to what should and what should not appear on the label or the bag. Typically, the information to be printed on the fertilizer bags consists of: (i) name of manufacturer/importer; (ii) brand name and trade mark; (iii) name of fertilizer; (iv) nutrient content in percentage terms on a dry-weight basis (N-P_2O_5-K_2O), and (v) gross and net weight. In the case of phosphate, the total and water-soluble P_2O_5 contents are usually specified.

Most bags also mention the words "use no hooks" for the information of farm labour and others to ensure that the bag and the product inside is prevented from possible damage during handling. Labelling specifications can change to reflect changing needs. For example, until a few years ago, manufacturers of S-containing fertilizers (e.g. AS and SSP) in India were not allowed to print the S content of the fertilizer on the bag. This has now changed and printing the specified S content on the bag is compulsory. In the case of biofertilizers, the expiry date of the product is normally stated on the package. Where this is not done, it should be made compulsory.

Packaging

Packaging specifications are usually a part of appropriate legislation and quality control. Proper packaging should ensure ease of handling and transport, reduction of losses and ability to withstand unfavourable weather conditions, while keeping product prices affordable within the conditions and constraints of the distribution system. At the same time, it should convey the right information to the users. Fertilizer distribution systems and requirements for storage and transport (including humidity) determine the quality of fertilizer packaging. It also has to take into account the chemical and physical properties of the products and conditions of storage, especially at the end of the distribution chain.

Pricing and subsidies

Pricing is an important factor that affects the farmer's acceptance of a product in terms of the investment needed and returns expected. Input pricing always has to be viewed in relation to the likely prices of the output in order to see that their use is remunerative. The choice between produce price incentives and input subsidies to stimulate production has long been a controversial issue. The majority of developing countries in Asia provide subsidies to inputs such as fertilizers, amendments and power in agriculture, while developed countries support agriculture using other mechanisms, often with indirect or invisible effects, and not always designed to stimulate production.

Other incentives to fertilizer use take the form of guaranteed support prices for agricultural produce, duty-free imports of fertilizer and tax exemptions for credit and investment in fertilizers and crop production. Such measures affect the profitability of external nutrient application and provide the required economic motivation for increasing crop production.

Subsidies given directly or indirectly to farmers for fertilizers and other farm inputs have been the most important pricing policy factor in many developing countries. Their effect in increasing plant nutrient demand is readily and clearly identifiable. In some cases, a particular nutrient (most commonly N) is subsidized while other nutrients are not. This leads to a distortion in balanced nutrient application as farmers tend to apply the subsidized nutrient in preference to the costlier unsubsidized nutrients regardless of the nutrients needed by their soils and crops. This not only results in imbalanced and inefficient nutrient use, but it also promotes the mining of soil nutrient reserves of the nutrients not being subsidized, and consequently the depletion of soil fertility. In the long run, such subsidies become counterproductive as the depletion of other nutrients starts to limit crop response. Therefore, it is important that fertilizer policies do not treat each nutrient in isolation but rather take a holistic view.

Financing

Building up favourable conditions for adequate financial support to the fertilizer trade and distribution (besides credit facilities to farmers) should be one of the major objectives of an effective plant nutrition policy. Fertilizer demand is often highly seasonal. The pattern of seasonal demand is different for nutrients such as P and K, which are given before planting, compared with N, which can be given in several splits during crop growth. Therefore, the cash-flow requirement of fertilizer traders is high, involving considerable amounts of money for which adequate commercial credit should be available in order for the supplies to reach rural markets well ahead of the application season. In several cases, manufacturers or other suppliers provide input to distributors on credit for varying durations. The distribution credit (credit given to dealers) and the production credit (credit given to farmers) both have a very important role in the marketing and distribution of farm inputs. The interest rates and other terms and conditions laid down by financial institutions have a strong bearing on credit offtake. A major recent initiative in the area of farm finance is the provision of special credit cards to farmers in India.

Transport and storage

Adequate transport and storage are part of the essential infrastructure needed to ensure an efficient use of fertilizers. Product planning and movement into an area, keeping in view the soil nutrient deficiencies and cropping pattern, have a major effect on achieving balanced and efficient fertilizer use. This requires effective coordination between research, extension and trade. In order to promote INM, suitable transport and storage facilities are needed, especially in the case of biofertilizers. This is particularly important for the viability of microbial inoculants in tropical and subtropical areas. The costs involved are a relevant factor for establishing the priorities to be assigned to the use of alternative means of transport. These often depend on the distance between the production site and area of consumption. In several cases, a fertilizer bag may require manual handling six or more times between the factory and the farm. In such cases, handling costs can even exceed the transport costs. Sound logistics and efficient handling and transport of materials can lower the storage costs by reducing the storage period. Effective policies need to focus on developing an effective and efficient transport and storage network to serve the needs of the region.

Marketing

The establishment and strengthening of a viable agricultural-input marketing system should be one of the major objectives of a plant nutrition policy. Fertilizer marketing normally involves three or four stages starting from the factory or port before the material reaches the farmer. The actual system used varies from one country to another and even from one company to another. In most cases, the marketing chain consists of: producer – wholesaler – retailer – farmer. The number of links used in the marketing chain is generally fewer in the case of private companies than in the case of government or institutional agencies. Fertilizer marketing systems should basically satisfy the farmer's requirements while being profitable for the marketer. These systems require the careful design and implementation of policies, in which the right balance of government and private participation in the production, import and distribution of fertilizers has to be found. This is a critical issue that is highly dependent on national economic and political conditions in many developing countries.

Effective marketing systems should promote efficient fertilizer use through balanced supplies backed by good extension advisory services. Farmers should be encouraged to heed soil-test-based recommendations and translate these into the right fertilizers with the help of extension services and industry agronomists. As the use efficiency of plant nutrients also depends on the status of other production inputs, a very positive development in several countries is the establishment of multi-input distribution enterprises and farm service centres. Such initiatives, in which a range of inputs (along with nutrient sources) and services are available to the farmers under one roof, need to be encouraged by policy-makers and financial institutions.

Extension and training

Extension and training systems consisting of demonstrations, training sessions, training materials and extension efforts on efficient crop production and nutrient management techniques are essential components of farm-support policies. Policy measures, especially for the developing parts of the world, need to have a strong orientation towards the augmentation of extension and training facilities. Extension requirements must be assessed and the services established properly on a country-specific basis in order to match the technological level and experience of the farming community. Adequate technological packages, including the balanced use of mineral fertilizers, as part of INM and basic knowledge of the economics of fertilizer use have to be introduced. Farmers should be brought to appreciate the contribution of sources other than mineral fertilizers and how these can be used for adjusting fertilizer recommendations. Research and extension efforts should provide motivation for farmers' increased participation in the development, testing and adoption of new technologies. They should also provide for receiving and taking into account feedback from the field on a regular basis.

It would be desirable to train farmers so that they can compute the nutrient balances of their farms. By doing so, they could adopt such INM practices that would minimize the depletion of their soils and also use locally available nutrient sources most productively in a pre-planned manner. Large-scale efforts would be needed to train extension field staff in the area of INM so that the essential expertise could be provided to the farmers. All such technologies to be transferred must meet the criteria of being technically sound, practically feasible, economically attractive, socially acceptable and environmentally safe.

Chapter 10

Plant nutrition, food quality and consumer health

GENERAL ASPECTS

Good quality is important in almost all harvested crop products be they food, fodder or industrial raw materials. Because high-value food or feed is an essential precondition for the health of humans and domestic animals, the influence of plant nutrient supply on the quality of foodstuffs is of considerable importance. Farmers want to produce good-quality products and sell them for a remunerative price while consumers want to buy nutritious and safe food as cheaply as possible.

The concept of quality is variable and any discussion on the subject should be based on a terminology that can distinguish between: (i) commercial quality, which determines the market price of the product, and (ii) nutritional quality or value, commonly called food value, which is relevant for health. Although the two concepts partly overlap, the respective priorities, namely, monetary vs health aspects, set them apart.

Commercial quality

The commercial quality of a product defines the price at the market and is based on easily recognizable properties that, to a certain extent, also indicate its food value. The price of food for direct consumption depends mainly on easily detectable characteristics. Food should appear attractive, clean, fresh and without blemishes. Usually, farm produce is classified according to the desired properties into commercial grades that determine the price paid to the farmer and, finally, by the consumer. Maintaining quality is also important with respect to the safe storage, ability to withstand transport and shelf-life of fresh foods and grains. This is to ensure that the product does not deteriorate because of any physical or biochemical defects.

In the case of products used for industrial processing, the specific concentrations of important ingredients, such as sugar, starch, protein, fat and oil, are important. Commercial quality requirements depend on the specifications of the output from the processing factory and they are assessed for special product properties based on easily measurable analytical data. The main features of commercial quality are: (i) external features, such as size, cleanliness and freshness; (ii) sensory features, such as taste, smell and colour; (iii) keeping quality and shelf-life during storage and transport; and (iv) concentration of special important ingredients, e.g. protein concentration for baking-quality wheat, and ingredients for industrial processing (starch, sugar and oil).

Food quality

The nutritional value, commonly called food quality, includes all substances that contribute to complete nutrition of humans and animals. Consumers desire attractive, wholesome, nutritious food that is free of harmful substances. The nutritional value of food is determined by adequate concentrations of about 50 essential ingredients required by humans and also several beneficial substances that must be taken up in balanced proportions and at regular intervals. According to medical expertise, about half of all human diseases are caused by inadequate or imbalanced nutrition. Therefore, special attention should be given to the concentrations of essential and beneficial substances in food.

Food quality should go beyond the supplies of energy derived from starch, sugar, oil and fat and the "pleasure" value derived from the taste and smell of food. Its main emphasis should also be on the essential and beneficial components required for the building and functioning of humans and animals. As sufficient uptake of these nutrients is a prerequisite for good health, their concentration in food is an important index of nutritive value. Food quality also includes safe food, which refers to the absence of health-harming substances. Good food should not contain: (i) excesses of plant nutrients that may be dangerous to health; (ii) toxic heavy metals from soils or from nutrient sources; (iii) toxic organic compounds, e.g. from organic waste materials; and (iv) radioactive contaminants.

The "health" value of foods is complex and remains hidden for consumers. Moreover, the damaging effects of poor food quality on health mostly appear over a long period of time and consumers tend to neglect this aspect. However, it should be of central importance for their present and future well-being.

Consumers rarely base their decisions on the actual nutritive value of the food but on easily perceivable food properties, such as taste and appearance. However, such perceptions can be misleading and harmful to the health in the long run. Taste is subjective and, hence, not suitable for objective food evaluation. In recent times, the aspect of "safe" food (not containing health-damaging or toxic substances) has been gaining more importance than the nutritive value in many developed countries. Consumers are becoming very sensitive to this aspect and some prefer certified safe food, produced in reliable production systems.

Importance of food quality

The quality of food products depends on many factors. It is influenced primarily by: (i) genetic factors that determine the basic quality, specific to the kind of crop; (ii) climate factors, such as light, temperature and water supply, that enable plants to approach their genetic potential; and (iii) an adequate and balanced supply of all plant nutrients, often achieved by external nutrient application through fertilizers and manures (discussed below).

In many developing countries, the importance of food quality is generally underestimated because the need for a sufficient quantity of food has often been considered more important than good quality. With increasing income levels and a better understanding of the role of nutritional factors, it is becoming increasingly clear that high food quality is as important as food quantity. Even with sufficient food, deficits of essential food components can cause malnutrition and other health problems. Typical examples are diseases resulting from deficiencies of protein, vitamins and mineral nutrients. Several deficiency diseases are widespread in developing countries and constitute a serious obstacle to the full development of their human potential.

Poor protein quality and a deficiency in total protein typically appears in small children after weaning, when their diet includes food that is rich in starch but poor in protein, such as that from cassava and other starchy foods. The resulting protein deficiency disease, called “kwashiorkor” (first described in Ghana), is a very serious illness and makes the person prone to infectious diseases. This health problem is more prominent in SSA than in Asian countries, where baby food is based mainly on protein rich cereals and pulses.

It is being increasingly recognized that a lack of mineral nutrients is responsible for special diseases with far-reaching consequences on the health of humans and animals. There are widespread and growing deficiencies of some micronutrients, such as Fe and Zn. In Southeast Asia and SSA, more than 75 percent of the population appear to be affected by Fe deficiency, half of them to the extent of having anaemia (Graham, Welch and Bouis, 2001). Although not always detected, vitamin deficiencies appear to be even more common. These lower human resistance to several infectious diseases. They are widespread in many developing countries.

Perceptions of food quality

In addition to the unsatisfactory comprehension and evaluation of food quality by many consumers, food quality is also an area of many prejudices as many people have their own personal experiences about the relationships between eating and health. Several common questions are regularly raised on these issues. Some such questions followed by their answers are given below.

Question: Does food quality increase or decrease with the adoption of modern crop-production technologies, especially with respect to mineral fertilizers?

Answer: Although critics claim that the increased use of mineral fertilizers reduces crop product quality, this is not the case. Most such critics oppose anything produced by using fertilizers because of their opposition to manufactured inputs in general. Most fertilizers are derived from natural products, which are concentrated and processed only to be more effective. Moreover, nutrients in all sources whether organic or mineral must be converted finally into inorganic ionic forms (Table 6) in order to be usable by plant roots. Phosphate and potash fertilizers are obtained from natural products such as PR and salt deposits. Although mineral fertilizers are produced in factories, they are basically derived from natural minerals. Even nitrogenous fertilizers, although largely synthetic chemicals, obtain their N from atmospheric air and finally deliver it in the same mineral form (nitrate) as do "natural" organic manures. Synthetic nitrate is completely identical to nitrate derived from humus. Thus, the argument of organic farming that synthetic N fertilizers should not be used in order to obtain a high-food quality is not justified (discussed below).

Question: Do so-called intensive production methods aimed at high yields inevitably lower food quality?

Answer: Regardless of the yield level or intensity of cultivation, not all the valuable components of a crop product can be increased simultaneously. Where the starch concentration of grain is increased, the protein concentration or another component may be lowered, or vice versa. Even an increase in the total amount of vitamins per plant may result in lower percentage concentrations owing to the dilution caused by relatively higher starch and protein concentrations or biomass. The dilution effect is principally important for quality considerations. However, its consequences should not be interpreted as a negative effect of yield-improving measures on quality, especially as this plays only a minor role in the medium yield range. With high yields, some components may be lowered to some extent by dilution, whereas others are increased. Higher yields contain greater total amount of nutrients even if their concentration is lower (total = concentration × weight). A well-known example of the dilution effect is the consumer experience that small fruits often taste better than large ones. This is because of a lower concentration of aromatic components that have not increased as much as the fruit weight.

Question: Can food quality decrease although the crop product quality increases?

Answer: Ideally, these two concepts should be identical. However, there can often be differences between them. Agriculture is responsible only for crop product quality, not for the changes in quality that occur during food processing in factories or during cooking in the kitchen. For example, whereas agriculture produces higher vitamin B_1 (thiamine) concentrations in wheat grain (higher crop-product quality), consumers obtain less vitamin B_1 (lower food quality) because of their preference for white bread. In Europe, the concentration of vitamin B_1 in bread made from wheat grain is now much lower than what it was decades ago. This decrease is not due to the increased use of mineral fertilizers. In wheat grain, the concentration of vitamin B_1 is connected closely to the protein concentration. With higher N fertilization, the concentrations of both have increased. The decline in vitamin B_1 in white bread is the result of the increasing refining of flour, where the starch-containing flour is separated from the bran, which is rich in valuable substances such as vitamin B_1 and minerals. The bran is used for animal feed. Therefore, consumers of brown or whole-wheat bread receive more vitamin B_1 than do consumers of white bread. If consumers prefer whiteness to nutrition, it is their choice, albeit not a nutritionally sound one. Awareness of such factors can influence the type of flour used for bread-making. However, agricultural practices can be modified to meet the requirements of food processing, e.g. using SOP instead of MOP for potatoes.

PLANT NUTRITION AND PRODUCT QUALITY

Because only properly nourished plants can provide products of overall high quality, any fertilization that improves the supply of plant nutrients from deficiency to the optimal range raises the amount of nutritional substances. However, it is impossible to increase the concentrations of all valuable substances simultaneously.

The nutrient supply required for high crop yields and for good food quality is nearly similar. In certain cases, e.g. baking quality of cereals or additional nutrient supply for highly productive animals, high-quality food and feed is produced by keeping supplies of some plant nutrients in the luxury supply range.

The relationship between nutrient supply and the resulting change in quality of crop products has largely been established. In assessing the effects of added nutrients on produce quality, it should be remembered that: (i) increasing the nutrient supply from deficiency to the optimal range usually results in better produce quality; (ii) increasing supplies from optimal to the luxury range may increase, maintain or decrease quality; and (iii) extreme increases in supplies into the toxicity range reduce quality and must be avoided. Nutrients differ in their roles in plant production and produce quality. Such effects are discussed in brief below.

Nitrogen supply and product quality

The addition of N generally has the greatest effect on plant growth and also considerable influence on product quality, especially through increases in protein concentration and its quality. It also increases the concentration of several other valuable substances. However, where the N supply is excessive, harmful substances may be formed that decrease quality. Various N compounds in plants are important for quality assessment. The manner in which these are affected by N supplies is summarized below:

- Nitrate: Form of N taken up from soil; basis for protein synthesis; nitrate concentrations of plants are generally low, but it may be accumulated.
- Crude protein: This is an approximate measure of protein and some other N compounds. Crude protein concentration = N concentration × 6.25. The concentration of crude protein in wheat grain may be raised from 10 percent to more than 15 percent, thus improving the "baking quality" of the flour.
- Concentration of pure protein increases up to the optimal N supply level despite some counteracting dilution effect. Pure protein can be divided into several fractions:

  - Prolamine and gluteline (low-value protein). Gluten is important for baking quality. N supply increases the prolamine content in grains, thus increasing the gluten concentration of grain kernels, which improves baking quality.
  - Albumin and globulin (high-value protein), containing many essential amino acids. The concentration of albumen, which has high nutritional quality, increases with the concentration of pure protein.
- Essential amino acids: Nine protein constituents that are vital for humans and must be contained in food. Their concentration determines the biological value of the protein, expressed by the Essential Amino Acid Index (EAAI). Vegetable proteins have values of 50–70 percent compared with 100 percent in case of egg protein. The concentration of essential amino acids often increases up to the optimal N supply level, but it sometimes decreases through dilution, especially where there is luxury N consumption.
- Amides: These are important storage forms of N (e.g. asparagine or glutamine) found in leaves and vegetative reserve organs. Amides have only small nutritional value for humans, but, if heated, may produce substances with an undesirable odour. They can be a source of protein for ruminants.
- Amines: Various N-containing compounds present in small concentrations in plants. Some, e.g. choline, have important functions, whereas others, e.g. nitrosamines and betaine, are unwanted.
- Cyclic N compounds such as chlorophyll; N-containing vitamins such as vitamin B_1; alkaloids, such as nicotine in tobacco; purine derivates, such as theobromine in cocoa.

Where N supplies are excessive, some unwanted N compounds may accumulate in vegetative plant parts. These are primarily the unutilized nitrate and amines. Nitrate can accumulate in leaves, especially where light intensity is reduced. Concentrations of nitrate-N (in dry matter) in vegetables should not exceed 0.2 percent in salad vegetables or 0.3 percent in spinach because of the risk of nitrite formation. Nitrite, which usually occurs in insignificant amounts, can be formed in leaves under reducing conditions, e.g. where spinach is stored without access to air. When food high in free nitrate is consumed, it may cause methemoglobinaemia. The best way to keep nitrate concentrations in vegetables low is to restrict N fertilization to a medium level and to apply total N in splits.

Nitrosamines are formed from nitrite and secondary amines and some are carcinogenic (e.g. diethylnitrosamine). Their concentration in plants is normally insignificant and not a health problem. Betaine is an important constituent of the so-called “detrimental nitrogen”, which interferes with the crystallization of sugar from the juice of sugar beets and, thus, reduces sugar yield.

An increase in N supplies also causes several types of changes in other substances, e.g.: (i) the concentrations of carotene and chlorophyll increase up to the optimal N supply; (ii) the concentration of vitamin B_1 in cereal grains increases until luxury N level; (iii) the concentration of vitamin C (ascorbic acid) decreases owing to the dilution effect; (iv) the concentration of oxalic acid, a harmful compound, increases in vegetables leaves (for human consumption) and in sugar-beet leaves (used as fodder for cattle), especially after fertilization with nitrate-N; and (v) the concentration of HCN in grass increases slightly – while its normal concentrations appear to promote animal health, higher doses are toxic.

Thus, the concentrations of all N fractions increase with higher N supply, but in different ways. The highest biotic value is obtained in the optimal supply range. Luxury N supply improves only certain quality components and this is often accompanied by quality reductions of other kinds. Thus, intensive fertilization of cereals with N may improve baking quality, but it lowers the average protein value.

Because plants normally absorb nitrate independently of the source from which it is applied, a direct influence of the form of N applied cannot be expected. However, where ammonium is applied and managed so that this is the form taken up by the plant, the nitrate concentration in leaves can be kept low. This can be achieved also by using slow-release fertilizers and nitrification inhibitors wherever their use is feasible and economic. Other influences observed on the qualitative composition resulting from the application of different N forms are mainly caused by side-effects, such as changes in soil pH.

Phosphorus supply and product quality

Owing to its many important roles in plant metabolism, the supply of P plays a central role in crop quality. Important quality indicators with respect to P are: (i) the P concentration and the composition of the plant P fraction; (ii) the concentration of other valuable substances that increase with better P supply; and (iii) the concentration of toxic substances that are often lower with increased P supply.

The major P-containing compounds that are important for crop quality are:

- Phosphate esters: These are the products of phosphorylation, i.e. bonding of phosphate anions as phosphoryl group ($-H_2P0_3$) to organic molecules like sugars ($R-O-H_2PO_3$).
- Phytin: This is the main organic form of phosphate storage (Ca-Mg-salt of phytic acid, i.e. inositol hexaphosphoric acid). Phytin is the main P reserve of seeds and can constitute up to 70 percent of total P. The proportion of phytin in vegetables such as potatoes is about 25 percent, and phytin, like inorganic P, is utilized by all animals, but best by ruminants. However, for humans, phytic acid may reduce the bioavailability of Fe and Zn.
- Phosphatides or phospholipids: These are important constituents of cell membranes that contain phosphoryl groups (e.g. lecithin, a glycerophosphatide). These form only a small portion of total plant P.

The P concentration of food and fodder is an important quality criterion because insufficient P intake causes “bone weakness” and deformations, which were common in cattle before the use of mineral P fertilization. In contrast to N, the P supply to crops remains in the “normal” range and rarely reaches the luxury range on most soils. In other words, there is practically no danger of overfertilization with P, which may cause problems owing to excess phosphate in food or feed.

When the P supply increases from deficiency to the optimal level, the total P concentration increases in the vegetative and reproductive parts, thus improving crop quality. The concentration of nucleic P increases only slightly, while the concentration of phosphatide-P remains approximately constant, and both occur in low concentrations. There is also a higher concentration of other value-determining substances, such as: (i) crude protein in green plant parts and essential amino acids in the grains; and (ii) carbohydrates (sugar and starch) and some vitamins, e.g. B_1. Seed quality improves with P nutrition, which results in greater seedling vigour. On the other hand, the concentration of some other substances such as nicotine in tobacco, oxalic acid in leaves or coumarin in grass can be reduced.

Potassium supply and product quality

Among plant nutrients, K is very closely associated with crop quality. It is required for good growth as well as for good crop quality, plant health, tolerance to various stresses and seed quality. By greatly affecting enzyme activity and through osmotic regulation, K affects the entire metabolism of the plant, especially photosynthesis and carbohydrate production. It improves the quality of several products including tubers, fruits and vegetables.

Increasing K supplies to plants up to the optimal level brings about the following changes:

- The concentration of carbohydrates increases owing to intensified photosynthesis, which results in larger concentrations of sugar, starch, fibres (cellulose), and also of vitamin C.
- The concentration of crude protein is reduced although the total amount is increased. This results from the dilution effect owing to the relatively greater increase in carbohydrate content. However, the more valuable fraction of pure protein may sometimes increase.
- The concentration of vitamin A and its precursor, carotene, increase.
- Losses of starch-containing tubers, such as potatoes, during storage are reduced through the prevention of decomposition of starch by enzymes.
- Unwanted “darkening” of potatoes is reduced. This phenomenon is caused by the formation of melanines and is particularly pronounced where K is deficient. Proper K supplies also prevent “black spotting” of potatoes upon cooking.

Unlike P, the K concentration is not a quality-determining component. Food usually contains more K than is required by humans or animals. Luxury supply of K in leaves may occur as a result of high K uptake. This is not detrimental but excess absorption of K by plants tends to reduce the uptake/concentration of Ca, Mg and Na, resulting in an imbalanced supply of these regulators of cell activity. K-induced Mg deficiency can decrease crop quality. On grassland, this can result in Mg deficiency in grazing animals.

Some effects of K fertilizers on crop quality are not caused by K itself but by the accompanying anion such as chloride or sulphate. Application of potassium sulphate results in a higher starch concentration in potatoes than where potassium chloride is applied. This is because chloride disturbs the transport of starch from the leaves to the storage organ (tubers). Similarly, in the case of cigarette tobacco, potassium sulphate is the preferred source of K over potassium chloride because excess chloride can reduce the burning quality of the leaf.

Calcium supply and product quality

A good Ca supply is essential for osmotic regulation and pectin formation. The Ca concentration of food and fodder is important for a proper balance of the major cations. Adequate supplies of Ca prevent a number of crop quality problems, such as inner decay of cabbage, brown spot and bitter pit in apples, and empty shells in groundnuts. Although Ca supply may not increase the oil content in groundnut, the total oil yield increases as a result of the favourable effect of Ca on kernel yield. Many of the benefits of liming on crop quality stem less from Ca itself but more from indirect effects caused by changes in soil pH that increase the supplies of other elements.

Magnesium supply and product quality

A good supply of Mg increases the concentration of carbohydrates and also chlorophyll, carotene and related quality components that are important for grazing animals. The Mg concentration is an important quality criterion because the major cations (K, Ca and Mg) should be balanced in order to ensure the best nutritional quality in cereals. Adequate Mg increases grain size and boldness. It is also reported to increase the oil content in oilseeds. For example, excess K in grass can result in Mg deficiency leading to hypomagnesaemia or grass tetany in grazing animals.

Sulphur supply and product quality

As S is an important constituent of some essential amino acids (cystein, cystine and methionine), S deficiency lowers protein quality. About 90 percent of plant S is present in these amino acids. Some plants (crucifers) contain S in secondary plant substances, e.g. oil, whose synthesis is inhibited where S is deficient. Mustard and onions rely for pungency and flavour on S-containing substances and these are also useful for increasing resistance against infections in the plant. An adequate supply of S improves: oil percentage in seeds; seed protein content; flour quality for milling and baking; marketability of copra; quality of tobacco; nutritive value of forages; grain size of pulses and oilseeds; starch content of tubers; head size in cauliflower; and sugar content and sugar recovery in sugar cane.

Micronutrient supply and product quality

Because micronutrients are involved in many metabolic processes, their adequate supply is a precondition for good food quality, especially with respect to the concentrations of proteins and vitamins. A survey of micronutrients in staple foods has been provided by Graham, Welch and Bouis (2001). The total concentration of the individual micronutrients is an important index of food and feed quality. However, some compounds containing micronutrients are utilized only partly by humans and animals.

Because the concentrations of micronutrients are not determined routinely, their average concentrations are often considered for nutritional purposes although these may give only an approximate idea of actual concentrations. For example, in leafy vegetables, a wide variation may occur. The following concentrations (in milligrams per kilogram of dry matter) range from marginal deficiency to luxury supply but are not toxic: Fe 20–800, Mn 15–400, Zn 10–200 and Cu 3–15. The consequences for health are clear. If a person is to be supplied with vegetables rich in Fe for better blood formation, then products with higher Fe concentrations are certainly preferable. Micronutrient concentrations should not be increased up to the toxicity level. Toxic concentrations are not only detrimental as such, but also negatively affect the composition of organic food constituents. The following comments on individual micronutrients relate to food quality:

- B is required in good supply for fruit and vegetable quality. B deficiency causes spots and fissures that substantially reduce produce quality and market value.
- Cu is required in optimal amounts for high concentrations and quality of protein and also to avoid spottiness in some fruits. A shortage of Cu partly combined with Co deficiency in grass retards the growth of grazing animals, and metabolic disorders manifest in the so-called “lick disease”.
- Fe in green-leaf vegetables such as spinach is an important source of Fe for humans. Soils with high pH tend to produce products low in Fe.
- Mn raises the concentrations of some vitamins, such as vitamin A (carotene) and C, in food and fodder crops. For good fertility, grazing animals require Mn concentrations that are about double those required for optimal grass growth.
- Mo deficiency decreases protein content and quality because of the important functions of Mo in BNF and N metabolism. Mo is also involved in the formation of healthy teeth.
- Zn is connected with plant growth hormones. Therefore, a good supply is required in order to obtain full-sized products, as in the case of citrus fruits. Compared with Cu, the optimal range of Zn is large but its toxicity can become a problem on soils with excessive Zn.

Excess micronutrients reduce food quality properties. However, this rarely is the case on most soils. An excess of chloride can aggravate salinity problems, adversely affect salt-sensitive crops and lower the quality of crops such as potato, tobacco and grapes.

Effect of toxic substances on crop quality

Good-quality food implies not only high concentrations of valuable substances but the absence or the presence of only insignificant concentrations (far below the critical toxicity limit) of harmful inorganic and organic substances. People want safe food that has no harmful components and does not cause health problems. There are increasing cases of pollution-related effects and risks associated with toxic substances that are taken up from the soil and endanger crop product quality.

In fact, there have always been problems with natural toxic substances in soils in certain areas. For example, high concentrations of Al are found in plants on very acid soils. These cause damage to plants and possibly also health problems to animals. However, with proper soil fertility management practices such as liming, the Al concentrations in plants can be kept at a low and insignificant level. Other substances in toxic amounts occur locally in small areas with high natural soil concentrations, e.g. Se, As and Ni, and these can cause health problems. A large-scale As-related toxicity problem has been reported in Bangladesh, where tubewell waters high in As are used for irrigation.

The danger to health from pollution can be either from the polluted atmosphere or from products used as soil amendments and nutrient sources that may contain harmful substances. A source of major concern is the disposal of toxic wastes and effluents on agricultural lands disregarding optimal application rates without adequate and proper treatment. An element of major concern is Cd. Its concentration is 0.1–2 mg/kg in normal soils and about 0.05–1 mg/kg in plants. On heavily polluted soils, plant concentrations of more than 5 mg/kg may be reached, which is a toxic level in food products. However, Cd concentrations in plants do not depend entirely on total Cd concentrations in soil, but on available concentrations, which are largely determined by soil reaction. Therefore, on acid soils, the Cd concentrations can be reduced to a certain extent by raising the soil pH by liming. Other toxic heavy metals are Pb, Cr, Ni and Hg; none of these should be allowed to reach toxic levels in food.

Prevention of the accumulation of dangerous substances in crops in order to ensure safe food is of great importance. The potential problems related to organic toxic components are also a cause of great concern. Some potentially dangerous compounds are decomposed and, thus, eliminated in biologically active soils. However, some persistent ones are liable to be taken up by plant roots and may endanger food safety. Serious problems arise from the recycling of urban or industrial waste materials, which may be polluted by heavy metals and possibly by some toxic organic substances. While it is desirable to recycle these materials in order to preserve plant nutrients, strict limits must be set on such substances in order to ensure food safety because of the long-term effects caused by their accumulation in soils.

The responsibility for preventing these effects from occurring is not primarily that of agriculture but of municipal authorities and the industries that generate such wastes laden with undesirable elements and wish to dispose of them. Agriculture should use only safe urban and industrial waste materials that are practically free of toxic substances in order to promote sustainable crop production and to produce the secure food demanded by urban consumers. The need for “safe” waste materials will increase in future with growing urban populations. In fact, whether wastes are treated or not, these should be certified as “fit for agricultural use” before being applied to the soils.

The potential danger from radioactive materials should also be taken into consideration. Consumers need to realize that a certain level of radioactivity in food is unavoidable. Some natural substances like radioactive potassium (potassium-40 or ^{40}K) are ubiquitous in soils, plants, food, animals and humans, and are not harmful. However, excessive radioactivity in soils via heavy atmospheric pollution with strontium (Sr, e.g. strontium-90 or ^{90}Sr) or uranium (U) isotopes from deliberate or accidental nuclear reactions should be avoided. Radioactive fallout is absorbed by both roots and leaves. A useful countermeasure against their uptake from soils is the stronger fixation of the radioactive substances in soils and, thus, a decrease in their uptake. Higher phosphate and sulphate levels in soils are advantageous for this purpose because strontium phosphate and strontium sulphate are less available to plants than are Sr^{2+} ions.

CONSUMER HEALTH ISSUES AND FOOD QUALITY

High-quality nutrition is an important precondition for the health of humans and animals. It appears that about half of all diseases are caused by nutritional disorders. However, the consequences of many disorders remain hidden because of the complexity of the relationship between food quality and health and because of the time lag between cause and effect. Agriculture that produces healthy food contributes to the prevention of diseases and this aspect is often underestimated.

The effects of food quality on health can be assessed by determining the value of the ingredients in food products or by medical indices of health status where nutritional disorders are not directly observed. The problem of the latter is that of latent (slight or hidden) deficiencies, which occur much more frequently than do acute (visible) deficiencies.

Humans health based on essential nutrients in food

Similarly to essential nutrients in plants, essential nutrients in food also play an important role in the growth and development of humans. The progressive decrease in the incidence of tuberculosis in the United Kingdom between 1880 and 1940 is a good historical example of the effects of better plant nutrition on human health, and this decrease is attributed partly to the improvement in food quality resulting from the introduction of fertilizers.

The ingredients that determine the nutritive value of food are:

- ➢ Essential substances: In addition to carriers of energy like starch, sugar and fat, about 50 other components must be present in food for good nutrition and health:
  - Amino acids: These are the building blocks of proteins. Out of 21 amino acids, there are nine that cannot be produced by the body and must be obtained from food. These essential amino acids are: leucine, valine,

TABLE 41
Essential mineral nutrient elements besides N and S, daily requirements and the effects of deficiencies

Mineral nutrient	Daily adult requirements	Major deficiency symptoms in humans and domestic animals
Na + Cl	5 g	Dehydration (salt-loss syndrome), disturbance of kidney function (excess Na can aggravate hypertension)
P	1.5 g	Weakness of bones, skeleton deformities, rickets
K	2 g	Disturbances of growth and fertility, weakness of muscles, but K deficiency is rare
Ca	1 g	Bone stability reduced, neuromuscular disturbances
Mg	0.3 g	Cardiac insufficiency, grass tetany in cattle
Fe	10 mg	Anaemia (widespread, especially in women)
Zn	15 mg	Disturbances of body growth, healing of wounds, hair growth
Mn	3 mg	Disturbances of growth and fertility, skeletal deformities
Cu	2 mg	Anaemia, reduced fertility, damage to coronary blood vessels
I	0.2 mg	Disturbances of thyroid function (goitre problem)
F	2 mg	Caries (tooth decay).
Mo	0.1 mg	Dental caries
Se	0.05 mg	Necrosis of liver, eye damage
Co	-	Deficiency of vitamin B_{12}

lysine, iso-leucine, threonine, phenylalanine, tryptophane, methionine and histidine (only for children).

- Essential fatty acids: Linoleic acid, linolenic acid and arachidonic acid are lipid constituents and a person's daily requirement is about 7 g. Supplies of essential fatty acids do not appear to be a major problem in most cases.
- Vitamins: There are about 15 vitamins. The four fat-soluble vitamins are A, D, E and K. There are more than 10 water-soluble vitamins such as B_1, B_2 (riboflavin), B complex (a group of vitamins), B_6, B_{12}, C and H (biotin).
- Several mineral nutrients (listed in Table 41).

➢ Beneficial substances: Among the several plant constituents contributing to health and well-being are:

- Aromatic substances for good taste.
- Substances for better mechanical functioning of intestines, e.g. cellulose.
- Special ingredients, e.g. resistance-improving substances (antibiotics).

Major nutrients

The primary constituents of major nutrients for humans are C, H, oxygen, N, P and S (the same as plant nutrients). These form bulk of the carbohydrates, proteins, fats, oils and vitamins.

Daily protein requirements for humans are about 1 g/kg of body weight. Supplies of protein, especially of essential amino acids, that must be obtained from food appear to be about adequate in developed countries except in cases of unusual eating habits. In contrast, protein deficiency, especially among infants, is common in many developing countries with poor food supply. It results from both quantitative undernourishment with protein and inadequate protein quality (often a deficiency of lysine) and leads to kwashiorkor disease. Better N nutrition of crops resulting in more and improved protein supply to the population could be an effective measure for controlling the deficiency.

Vitamins

Vitamin A, derived from the photosynthetic pigment carotene, occurs mainly in green leaves, carrots, milk, and egg yolk. Lack of vitamin A is the most important cause of blindness in childhood and is still prevalent in some parts of South Asia. A good supply of vitamin A can be obtained from eggs and milk, but a sizeable portion of the population relies mainly on vegetable sources.

Vitamin B_1 (thiamine) occurs primarily in the germ of grain kernels. Its concentration increases with increasing N supplies. Lack of vitamin B_1 is associated with the disorder beriberi. The disorder can cause severe damage to the heart and muscles. The main problem of supplying thiamine to the population is not the production of foodstuffs (e.g. rice) rich in thiamine, but the trend towards refining, which often results in consumption of only the inner part of the rice grain leaving the germ of kernel out (e.g. polished rice). The technique of parboiling rice is helpful in retaining vitamin B_1.

Lack of vitamin B_2 (riboflavin) appears to be the most widespread deficiency and is often associated with insufficient protein intake. The acute symptoms do not appear very serious, but people become more prone to sickness in general.

Niacin (nicotinic acid) is a vitamin in the B complex group. It is found in meat, milk, eggs and wheat germ. People in areas where maize is the main food source are at risk of developing pellagra (a skin problem) and encephalopathy (mental illness) because maize is low in niacin. Furthermore, the niacin in maize cannot be absorbed in the intestine unless the maize is treated with alkali.

Vitamin C (ascorbic acid) occurs especially in fresh fruits and leaves. Some fruits such as citrus, guava and aonla (Indian gooseberry, *Emblica officinalis* Gaertn.) are exceptionally rich in vitamin C. Additional vitamin C beyond the daily requirement seems to improve resistance to several diseases, including the common cold.

Supplies of vitamins in food appear to be largely adequate in developed countries. Acute deficiencies (avitaminoses) have become a rarity, but hidden deficiencies (hypovitaminoses), mainly of vitamins A, B_1 and C, are common in certain population groups. In most cases, this lack of supply is not caused by their shortage in food but by consumers' eating habits, e.g. a preference for refined food, from which vitamins are partly removed. In developing countries, acute and hidden vitamin deficiencies are widespread and these may increase in the future. The consequences of such deficiencies are considerable, mainly in terms of reduced resistance to many diseases.

Minerals

While major mineral nutrients, such as Na, P and Ca, etc. have bee well studied, some micronutrients (often called trace elements in medical publications) have only recently attracted the attention of nutritionists and biochemists. Mineral nutrients are present in food either as salts or as organic compounds. Not only are their concentrations important, but so too is their bioavailability (the portion that is absorbable and utilizable). Moreover, substances that inhibit (e.g. phytic acid) or promote (e.g. some vitamins) nutrient bioavailability should be taken into account, as should certain antagonistic effects between minerals. The requirements for minerals and some pathological effects of mineral deficiencies in humans are listed in Table 41.

Two examples can illustrate the consequences of mineral nutrient deficiencies and their amelioration on health:

- Phosphate and bone stability: In the nineteenth century, P deficiency was widespread in Central Europe and so was "bone weakness" in cattle. In an area of Austria with a severe phosphate deficiency in the soil, people (especially women) had deformed bones (rickets). However, after several years of phosphate fertilization, these symptoms of deformities disappeared, resulting in considerable health improvement.
- Molybdenum and teeth stability: In about 1950, it was noticed that the teeth of children in Napier, New Zealand, were healthier than those of the children in the nearby town of Hastings, where there was a high incidence of tooth decay (caries). Investigation into causal factors showed that this was not caused by a lack of fluoride in the drinking-water. The difference was caused by a differential Mo supply to vegetables grown in gardens. The Mo supply was adequate in Napier but deficient in Hastings. Insufficient Mo in the vegetables resulted in weak teeth because Mo is required for the formation of stable dental enamel, which is a fluorapatite.

Resistance-improving substances

The resistance capacity of the human body to pathogens is one of the major determinants of health. It is improved by good nutrition, which in turn is enhanced by the intake of quality food, primarily obtained through a proper plant-nutrient-management-based crop production system. Well-nourished people, especially children, suffer much less from infectious diseases and have a much lower mortality rate than do malnourished persons.

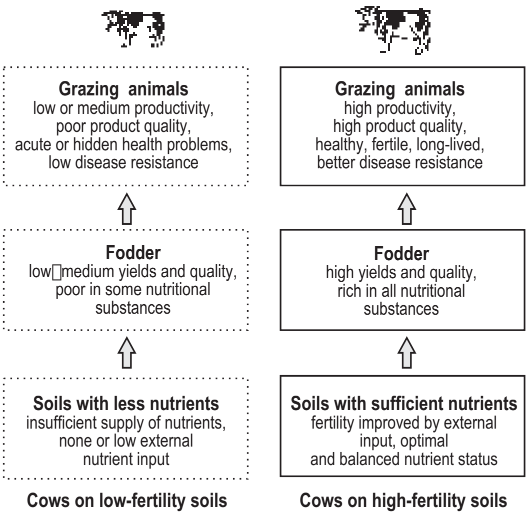
Resistance-improving substances can be mentioned as beneficial food ingredients. They are produced by certain fungi in fertile soils, composts, etc., where their concentrations are about: 5 mg/kg streptomycin, 0.1 mg/kg terramycin, and 0.02 mg/kg aureomycin. These antibiotics are taken up by plants and occur in low concentrations in the leaves, where they apparently act as protective agents against certain infections. Humans and animals may probably derive a certain natural resistance by eating these foods.

Animal health and feed quality

The relationship between food quality and health is best demonstrated by grazing animals. In contrast to humans, who generally have a variety of food, grazing animals are restricted to the fodder present in the pasture. The key to animal health

FIGURE 49

The effect of fodder quality, resulting from differences in soil fertility status and external nutrient supply, on the health and productivity of grazing animals



Source: Finck, 2001.

is an adequate and balanced supply of mineral nutrients obtained from the grassland fodder. Much information on human mineral-nutrient needs has been obtained from animal nutrition. Nutrient management of fodders, grasslands and pastures has been discussed in Chapters 7 and 8.

The nutrient supply level of soils, whether good or poor, is reflected in feed quality and has direct effects on animal growth, health and fertility and also on the quality of products such as milk, meat and wool. With grazing animals, the causal chain of soil – plant – animal is demonstrated clearly. This is further established through the well-known examples of phosphate deficiency in many countries and those of Cu and Co deficiencies in Northern Europe and Australia.

Major issues relating plant nutrient management and feed quality with animal health and productivity are:

- ➢ Low soil fertility of many grazing lands: Because grazing lands are often on soils with marginal fertility, their fodder productivity is often low or medium, and so is the quality. Figure 49 summarizes the relationship between soil fertility, fodder quality and the response of animals in terms of production and health. Salient examples of this kind are found in countries with large areas under severe nutrient deficiency. Co deficiency is an example. Solutions to such problems can be achieved through appropriate nutrient management.
- ➢ Higher nutrient requirements of very productive animals: For cattle with a high milk production, higher amounts of mineral nutrients are required. This should be taken into account either by feed improvement via fertilization or by supplementary feeding to promote animal health and fertility.
- ➢ Additional nutrient needs of animals: Animals require more essential nutrients than do plants. These nutrient elements should also be considered in evaluating feed quality. For example, Se deficiency does not affect plant growth but it causes serious health problems in grazing animals, particularly sheep. In such situations, the addition of such missing nutrients may not improve plant production but it will improve animal health and productivity.

When considering food quality, not only rational but also emotional aspects are encountered. Discussion on food quality should be on a rational scientific basis and not based on general beliefs or prejudices that originate from philosophical, religious or other ideas.

Most agricultural production systems with efficient plant nutrient management produce high-quality food. However, many consumers do not derive the full benefit from their food because of eating habits that neglect quality. This is unfortunate because high-quality food is produced for the consumers' benefit.

Consumers can rarely evaluate the nutritional quality of the food they purchase even where they are aware of the principles and facts of food quality. Many consumers would be happy if they could obtain certified, good-quality food produced in production systems designed for this purpose. They are even prepared to pay higher prices for such reliable food as this is considered a kind of "insurance" for good health.

The question arises as to whether food production systems can be adjusted to such demands of the consumers. Food of good quality can be produced on fertile soils using good crop management. This occurs on the majority of farms worldwide where adequate and balanced fertilization through integrating various sources is a part of crop production.

In order to produce acceptable and certifiable quality foods from a plant nutrition point of view: (i) the supply of nutrients from internal and external sources (INM) should be based on good soil nutrient supply, which is evaluated by diagnostic methods and on the nutrient demands of the crops; (ii) nutrient deficiencies should be overcome by appropriate fertilization with the goal of obtaining food with a high concentration of valuable components while avoiding quality problems caused by unwanted excess of nutrients; and (iii) there should be no harmful substances in the food.

Chapter 11

Plant nutrition and environmental issues

The influences of nutrient management on the environment relate to two broad issues. The first issue concerns the interaction of plant nutrient status with various soil and climate stresses, as discussed in Chapter 6. The present chapter examines the second issue relating to the effect of nutrients or other constituents of fertilizers and manures on environment quality, pollution, human health, etc.

Depletion or improvement in soil fertility is also a part of environmental degradation or improvement. Nutrient depletion from soils is a major form of soil degradation (FAO, 2003d). On a global scale, soil fertility depletion is far more widespread than is soil fertility improvement. Nutrient depletion destroys the productive capital of the valuable soil resource. Depletion of soil nutrients is caused primarily by negative nutrient balances, faulty nutrient management strategies and a lack of resources for investment in soil-fertility-enhancing inputs.

TABLE 42
Environmental issues in land and water development for 13 Asian countries

Environmental issue	Frequency of occurrence
Low fertility and imbalanced nutrition	13 (all countries)
Population increase, water and wind erosion	12
Land-use policies, sedimentation and siltation	11
Deforestation, waterlogging, shifting cultivation, land conversions	10
Salinization	9
Drought, acidity	8
Pollution, acid sulphate soils, organic matter depletion	7
Desertification, overgrazing, landslides	6
Poor crop management	5
Peat soils	4

Source: FAO/RAPA, 1992.

In a survey of 13 Asian countries (Bangladesh, China, Democratic People’s Republic of Korea, India, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam), soil nutrient depletion coupled with imbalance in soil fertility was the most frequently mentioned issue identified with land and water development in all the countries (Table 42).

BASIC EFFECTS OF NUTRIENT MANAGEMENT ON THE ENVIRONMENT

Nutrients added through fertilizers, manures and composts can have negative as well as positive effects on the environment depending on how poorly or properly these inputs are managed. The added nutrients may be absorbed by crops, immobilized by the soil or lost from the soil system. Depending on the nutrient and various conditions, these can be lost to the atmosphere by volatilization, lost through soil and water erosion, lost from the soil profile by leaching. Leached N can also be lost to the atmosphere through denitrification.

Positive and negative effects of nutrients

Positive effects

The positive effects of nutrients on the environment are:

- Efficient use of plant nutrients ensures that yields are higher than those obtained on the basis of inherent soil fertility by correcting either an overall deficiency or an imbalance of nutrients.
- Nutrients removed from the soil through harvesting and export of produce can be largely replenished through various types of recycling in order to maintain and enhance the production potential of the soil.
- By increasing yields per unit area from suitable arable land, application of plant nutrients allows land of low quality, e.g. land susceptible to erosion, to be withdrawn from cultivation. This reduces the overall pressure on land, including deforestation and overgrazing on non-cropped areas.
- Efficient use of plant nutrients eases the problem of erosion control on the cropped area because of the protection provided by a dense crop cover.
- Balanced plant nutrition also results in an increased addition of organic matter through greater leaf residues, and root and stubble biomass.
- Where balanced fertilization is practised, there is greater N uptake by crops and less nitrate is leached down the profile for the pollution of groundwaters or further loss through denitrification.
- INM promotes the correct management of all plant nutrient sources on the farm and helps reduce the losses of plant nutrients to the environment.

Negative effects

The negative effects of plant nutrients on the environment need to be considered both at high and low input levels.

At high levels of input use, the nutrients applied to the soil are not taken up completely by the growing crop even under the best conditions. Out of the remaining fractions, the soil constituents are able to bind and immobilize most of them so that they do not move freely with soil water and create possible negative impacts on the environment (water and air). Nitrate and, to a lesser extent, sulphate and B are not held strongly by the soil and can leach down with percolating waters and contribute to the undesirable enrichment of water. Phosphate generally moves very little way away from the site of application. Where it does, it is mainly through soil erosion or surface runoff. Over a period of years, phosphate applied through fertilizers or organic manures can move to deeper layers of coarse-textured soils in high rainfall areas. If it exits the soil profile and moves into waterbodies, its concentration increases and it can lead to excessive growth of algae, etc. and result in eutrophication to the detriment of other organisms. The relative importance of these phenomena depends on the physico-chemical and biological reactions in which the nutrients take part. Chapter 4 has presented details of the dynamics of individual nutrients in soils.

Table 43 summarizes the environmental problems associated with fertilizer use and general strategies to minimize them. Most of the problems, except those associated with Cd, are largely caused by the incorrect use of nutrients and their poor integration with other production inputs. This implies that most of the problems observed can be controlled if appropriate measures are taken.

The negative effect of levels of input use can be summarized as follows:

- The constant removal of crop produce without sufficient replenishment of plant nutrients exported by the crop causes a steady decline in soil fertility. This mining of plant nutrients, leading to severe depletion of soil fertility, is also a kind of soil degradation and a major environmental hazard in a number of developing countries (Table 42). The use of low levels of input places additional stress on soil nutrient supplies, resulting in excessive mining of soil nutrients and in depletion of soil fertility, leading to land degradation.
- To the extent that land and labour resources are available, low crop yields resulting from nutrient depletion force farmers to cultivate land under forests or marginal soils that are subject to erosion or desertification and, therefore, not normally fit for cropping. Bringing unsuitable land into cultivation promotes land degradation.
- Large areas of soils in the tropics are inherently poor in soil nutrients and suffer from problems of acidity, salinity, alkalinity and Al toxicity. Such soils can be made productive with appropriate amendments and a basic input of plant nutrients. Low or zero use of plant nutrients on such soils prevents the development of agriculture on a sustained basis. Organic recycling can only

TABLE 43

Environmental problems associated with fertilizer use and possible solutions

Problem	Cause mechanism	Possible solutions
Groundwater contamination	Leaching of weakly held nutrient forms such as nitrate (most important), chloride, sulphate and boric acid.	Balanced use of fertilizers; optimal loading rates of animal slurry, organic manure and wastewaters; improved practices for increasing N efficiency; including use of nitrification inhibitors, coated fertilizers and deep placement of N fertilizer supergranules where economic; integrated N and water management.
Eutrophication	Nutrients carried away from soils with erosion, surface runoff or groundwater discharge.	Reduce runoff, grow cover crops, adopt water harvesting and controlled irrigation, control soil erosion.
Methaemoglobinaemia	Consumption of high nitrate through drinking-water and food.	Reduce leaching losses of N, improve water quality.
Acid rain and ammonia re-deposition	Nitric acid formed by the reaction of N oxides with moisture in the air, ammonia volatilization and sulphur dioxide emissions.	Reduce denitrification, adopt proper N application methods to reduce NH_3 volatilization, correct high soil pH, increase CEC by organic additions.
Stratospheric ozone depletion and global warming	Nitrous oxide emission from soil as a result of denitrification.	Use of nitrification inhibitors, urease inhibitors, increase nitrogen-use efficiency, prevent denitrification.
Itai-itai (ouch-ouch) disease	Eating rice and drinking water contaminated with Cd.	Soil management such as liming or water control in rice fields, monitoring Cd content of PR and finished fertilizers.
Fluorosis in animals	Ingestion of soil or fertilizer treated with high fluoride PR.	Monitor the F content of PR applied directly to acid soils.

Source: Modified from Pathak *et al.*, 2004.

partially solve the problem as the biomass produced on poor soils is itself extremely poor in essential plant nutrients.

Effective management practices can prevent or remedy the negative effects of the applications of plant nutrients, both at low and high levels of input. Optimal fertilization can overcome the problem of nutrient depletion and of mining soil fertility. Judicious management of plant nutrients can prevent pollution, mainly through practices that reduce losses of nutrients into the aquifers or the atmosphere. This can be achieved through balanced, timely, targeted fertilization such as SSNM combined with other practices (e.g. improved varieties, water management, and plant protection) that stimulate maximum uptake of plant nutrients by the crop. At the same time, due attention should be given to controlling losses through soil erosion, runoff and land management.

The excessive use of inputs is not advised under any circumstances by scientific farming. High-input application is only justified where the nutrients are balanced and used efficiently. These are also justified only where the crop varieties grown can use the "high input" to achieve high production. Towards this end, farmer education is of utmost importance because these measures have to be taken by individual farmers, often on very small landholdings. INM is an excellent approach for such improvement at all productivity levels if farmers are advised properly.

ENVIRONMENTAL ASPECTS OF PLANT NUTRIENTS

Nitrogen

Nitrogen losses

Of all the inputs, N additions have had the single largest effect on crop yields and also have contributed most to environmental concerns, discussions and problems. Added N that is not absorbed by the crop or immobilized by the soil can be lost from the soil by various means. These include: leaching of nitrate to groundwater; and volatilization of ammonia into the atmosphere and as nitrous oxide (NO) to the atmosphere resulting from denitrification of nitrate by soil organisms. In addition to these, soil and applied N can also be lost through soil erosion and surface runoff.

The magnitude of these losses varies greatly between systems and environments. It is necessary to be aware of the validity of various estimates and the errors associated with them, as highlighted by the relative errors associated with the computation of N and P balances on farms in the Netherlands. For example, the error associated with fertilizer input was 1–3 percent, that with manure input was 10–20 percent, but errors of 50–200 percent were associated with losses through leaching, runoff or volatilization (Oenema and Heinen, 1999).

Mineral fertilizer supplies about 50 percent of the total N required for global food production. Global fertilizer N consumption was 84.7 million tonnes N in 2002 (FAO, 2005). The contribution of N through other crop production inputs is estimated as: BNF, about 33 million tonnes; recycling of N from crop residues, about 16 million tonnes; animal manures, about 18 million tonnes; and atmospheric deposition and irrigation water, about 24 million tonnes (Smil, 1999).Of the about 170 million tonnes N added, about half is removed from the fields as harvested crops and their residues. The remainder is incorporated into SOM or is lost to other parts of the environment, for which global estimates of individual loss vectors are highly uncertain (Mosier, Syers and Freney, 2004). About 47 percent of the applied mineral N (39.8 million tonnes) is lost to the environment every year (Roy, Misra and Montanez, 2002).

Fertilizers, organic manures, crop residues and crop management (as also the water input) have a major influence on N losses. In flooded-rice cultivation, it is common that 20–30 percent of the applied N is unaccounted for (lost) after crop harvest. Often, a sizeable portion (30–50 percent) of the applied N remains in the soil and only a small proportion of this is recovered in the following crop. Except for the natural leaching of soil nitrate as a result of rain and snow, most other reasons can be attributed to inadequate fertilization practices and poor water management.

Nitrate leaching

Nitrate is not bound by soil particles and remains in the soil solution where it moves freely with the soil water. Even where the N is applied in the ammonium or amide form, soil bacteria readily transform it under aerobic conditions to nitrate. Given that most N fertilizers are readily soluble, there is generally an excess supply of N immediately after application. The amount that is not taken up by the plant or immobilized by the soil is susceptible to loss. Considerable quantities of nitrate can also be lost from the mineralization of SOM, organic manures, animal slurry and crop residues. This generally occurs soon after harvest. Losses from animal manures are important contributors to nitrate losses in some areas. Leached nitrate can originate from any potential source.

Nitrate lost by leaching or transported in surface runoff can result in increased nitrate concentrations in drinking-water, eutrophication of surface waters and increased production of NO. It has been estimated that the groundwater under some 22 percent of the cultivated land in the European Union (EU) has NO_3^- concentrations exceeding the EU upper limit of 20 mg/litre. Similar high concentrations are found in many parts of the United States of America and other countries. Factors contributing to nitrate leaching to groundwater are:

- coarse-textured or extensively cracked soils;
- high concentration of nitrates in the soil profile as a result of excessive applications of N through fertilizers and manures;
- heavy rainfall that moves nitrates downward;
- restricted plant rootzone (due to plant species, time of year) to intercept nitrates for crop use;
- high water table;
- uncontrolled flood irrigation.

Not all of the above conditions have to be met for nitrate leaching to occur. However, nitrate leaching is at its maximum where all these factors exist and minimum where the reverse is the case. A deep and extensive root system enables crops to utilize N more efficiently, thus minimizing the risk of leaching. Leaching losses of N can be very high where N is applied to crops that have a shallow root system or that contain a small amount of N in the produce.

Nitrate leaching has another associated negative effect. When leached, all anions (nitrate, sulphate and chloride) take along with them equivalent amounts of cations. Therefore, nitrate leaching can deplete the soil of exchangeable cations such as Ca^{2+}, Mg^{2+} and K^{+}. The total N loss through leaching consists not only of N loss but also basic cations, which can increase soil acidity.

Emissions of ammonia

Ammonia volatilization from soil and vegetation contributes about 21 million tonnes/year of N (Smil, 1999). The global ammonia loss from mineral fertilizers is estimated at 11 million tonnes N (14 percent of mineral N-fertilizer use) (FAO/IFA, 2001). The loss from animal manure is about 8 million tonnes N/year (23 percent of animal manure N use). The global NH_3 loss from the use of mineral N fertilizer in wetland rice cultivation amounts to 2.4 million tonnes (20 percent of the 11.8 million tonnes of N applied to wetland rice). In grasslands, the annual global use of mineral N fertilizer is 4.3 million tonnes, with estimated loss rates of 13 percent for developing countries and 6 percent for developed countries (FAO/IFA, 2001).

The highest emissions of ammonia are in regions with intensive animal production activity (Europe), widespread use of urea (India,) and application of ammonium carbonate fertilizer (China). The dominant source of ammonia emission is animal manure as about 30 percent N in urine and dung is lost through this route.

Ammonia volatilization losses from surface-applied urea can amount to 25 percent on pastures and up to 50 percent in flooded rice. In a study on perennial dairy pastures in southeast Australia, losses of up to 45 percent of applied N have been recorded, and the magnitude of loss was affected by the N source used (Eckard *et al.*, 2003). Ammonia volatilization losses could be substantially reduced in summer by applying ammonium nitrate rather than urea. However, the approximately 45-percent cheaper unit price of N in urea compared with ammonium nitrate favours urea application on an agro-economic basis.

Factors favouring ammonia volatilization are:

- high soil pH (> 7.0);
- soils high in calcium carbonate (lime);
- soils with low retention ability for ammonium, e.g. low clay content, low organic matter, low CEC;
- high soil or atmospheric temperature;
- liquid fertilizer applied onto dry soil;
- high wind velocity and/or highly aerated soils;
- high rate of fertilizer or manure application;
- shallow (< 2 cm) depth of incorporation/penetration.

In arable soils, ammonia volatilization can be severe from surface applied urea that is not incorporated on neutral to alkaline soils during hot and dry periods. Such losses can be reduced substantially by incorporating urea in a moist but not very wet soil. Ammonia that is volatilized into the atmosphere returns back to earth with rain and snow as a part of the N cycle.

Volatilization of ammonia from liquid animal manure represents a significant cause of N loss. The magnitude of this loss depends on a number of factors including the method of application. In Canada, Manitoba Agriculture, Food and Rural Initiatives (http://www.gov.mb.ca) estimated the losses as shown below:

- broadcast, no incorporation for 2–3 days: N loss, 25–35 percent;
- broadcast, followed by incorporation within 2 days: N loss, 15–25 percent;
- broadcast, no incorporation on cover crops: N loss, 35 percent;
- injection: N loss, < 2 percent);
- irrigation within 3 days: N loss, 25–35 percent.

Where time to incorporation exceeds three days, N losses can be 40–60 percent with broadcasting and 60–80 percent with irrigation. For solid manure, volatilization losses from broadcasting may be less than those reported for liquid manure.

Emissions of nitrogen gases

Emissions of N gas in elemental form or as various oxides such as nitrogen dioxide (N_2O) and NO_2 occur on a large scale. Large amounts of the inert N_2 gas are emitted as the end product of denitrification. However, apart from reducing the nitrogen-use efficiency of crops, it does not have any negative environmental impact.

Both NO and N_2O are produced by soil microbes breaking up nitrate under conditions of low oxygen supply (waterlogged soils). The process is known as denitrification. Factors conducive to denitrification are: (i) soils with high organic matter (5 percent or greater); (ii) limited oxygen, due to high water content, rapid respiration or compaction; (iii) neutral or alkaline pH (7.0 or greater); and (iv) temperatures above 20 °C. N gases released by denitrification react with volatile organic compounds in sunlight to form ozone (O_3). This is the principal gas that shields the earth surface from ultraviolet radiation from outer space but which can be damaging to crops at low concentrations.

Denitrification losses as gaseous dinitrogen (N_2) amount to about 14 million tonnes/year, and N_2O and NO from nitrification/denitrification contribute about another 8 million tonnes N to the total loss (Smil, 1999). One study (FAO/IFA, 2001) estimates the global annual N_2O and NO emissions from agriculture as 3.5 and 2.0 million tonnes, respectively. The mineral fertilizer induced emissions for N_2O and NO amount to about 1.25 million tonnes/year, while the figure for animal manure induced emissions is about 0.32 million tonnes/year.

It is estimated that N_2O contributes 5–6 percent to the present greenhouse gas effect. Chemodenitrification (denitrification without microbial activity) requires low pH, but may be significant in freezing soils with high salt concentrations and high nitrite content. Denitrification cannot take place without nitrate. It can be prevented by avoiding high applications of N to arable areas with high water tables, by avoiding intermittent ponding, by the use of nitrification inhibitors and by deep placement of fertilizer/supergranules where feasible.

Phosphorus

Phosphate occurs in soil in both organic and inorganic forms that differ greatly in terms of their solubility and mobility. P applied through mineral fertilizers is in inorganic forms of varying solubility. Even at optimal rates, the use of mineral fertilizers and organic manures can lead to a buildup of soil P over time. The P thus retained is beneficial rather than harmful as it improves soil fertility and crop productivity.

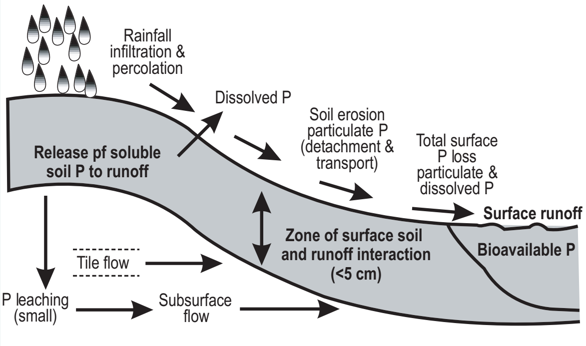
The N:P_2O_5 ratio in most animal manures is about 1:1 whereas plants remove about 2.4–4.5 times more N than P_2O_5. Such residual organic forms of P are free to move with soil water in much the same way as nitrate and they can be leached. In this respect, these are different from fertilizer P or the more stable forms of organic P that are a part of SOM. On the other hand, inorganic forms of P are bound strongly to clays and oxide surfaces in acid soils, and precipitated as relatively insoluble calcium phosphates in alkaline soils. These bonding and precipitation mechanisms keep the P concentration in the soil solution at a low level; hence, leaching and surface runoff of phosphate in solution does not generally contribute to eutrophication. However, P bound to soil particles can be lost through soil erosion.

The P that can contribute to the enrichment of waterbodies, and hence lead to eutrophication, is a combination of the P that is attached to soil particles less than 0.45 µm in size that are transported during soil movement. Figure 50 shows the movement of P in surface water flow. The risk of P losses to the environment through surface runoff is greatest on sloping lands, and where the fertilizer is surface applied and then followed by rainfall or irrigation.

Most governments have set limits on the concentration of P in waters. In the United States of America, the Environmental Protection Agency has recommended a limit of 0.05 mg/litre total P for controlling eutrophication in streams that enter lakes and 0.1 mg/litre for total P in flowing streams. It has not been possible to prescribe safe P concentrations in runoff leaving a field because of the considerable P transfers that occur between the field and the waterway. Grassed riparian strips are recommended for trapping particulate P.

FIGURE 50

The movement of P in surface water flow



Source: Mullins, 2001 (available at www.ext.vt.edu).

Phosphate leaching is only a problem on soils that are well supplied or oversupplied with P, especially where they have inadequate capacity to immobilize P. Maintenance of good soil cover is the best protection against such losses. Subsurface leaching of P can take place where: (i) P is in soluble organic form, as in manure; (ii) the capacity of the soil for binding inorganic P has been exceeded; and (iii) a preferential flow of water through channels and cracks in the soil prevents contact with the adsorption sites in the soil (Laegreid, Bockman and Kaarstad, 1999). With good nutrient management, the phosphate losses to the environment can be kept low and with in a tolerable range.

Other nutrients

Losses of K, Ca, Mg and S to the environment are not considered very important. Deficiencies of some or all of these nutrients result in poor plant growth and the increased risk of soil erosion. Losses of basic cations can occur along with the leaching of anions such as nitrate and chloride. In general, leaching losses are greater where soluble nutrients are not fully utilized by the crop and the soil particles do not have sufficient capacity or reactive surfaces to adsorb them. K can be lost through leaching from coarse-textured soils under heavy rainfall or flood irrigation. The loss of K through leaching and erosion is a waste of resources but it is not known to constitute any environmental or health hazard.

Sulphate is relatively more mobile than nitrate or chloride but much less so than phosphate. S that has leached from the topsoil and accumulated in the subsoil can be utilized by deep-rooted crops in a later season. However, S can be lost through leaching in shallow soils or soils without sufficient retention capacity, but it is not associated with environmental or health problems. Unlike nitrate, the World Health Organization (WHO) has made no recommendations regarding the limits of sulphate concentration in drinking-water. In highly reduced soils, S can be lost to the atmosphere as hydrogen sulphide (H_2S).

B dissolved in soil water occurs as the water-soluble boric acid (H_3BO_3), which can be lost by leaching. The pumping of B-rich groundwaters for irrigation is not advised as it can add excess of B to the soil, leading to possible B toxicity. The upper limit of B in irrigation water in heavy-textured soils is 2 ppm B for semi-tolerant crops and 3 ppm B for tolerant crops. For coarse-textured soils, these limits are 3 ppm B and 4 ppm B, respectively (Yadav and Khera, 1993).

All nutrients can be lost by surface runoff and water and wind erosion where the nutrients are soluble and the soil particles containing them are detached and transported. Although these are a loss to the site from where they are removed, a significant part of such losses can be intersite transfers to the extent these are deposited at another site along the way. Many alluvial soils owe their fertility to the soil brought in with surface runoff, e.g. during floods.

Soil contamination from nutrient sources

In addition to the essential nutrients applied through minerals, finished fertilizers and manures, incidental additions of undesirable substances can also take place.

TABLE 44
Chemical analysis of potentially hazardous elements in sedimentary phosphate rocks

Country	Deposit	Reactivity	P_2O_5	As	Cd	Cr	Pb	Se	Hg	U	V
			(%)	(mg/kg)					(µg/kg)	(mg/kg)	
Algeria	Djebel Onk	High	29.3	6	13	174	3	3	61	25	41
Burkina Faso	Kodjari	Low	25.4	6	< 2	29	< 2	2	90	84	63
China	Kaiyang	Low	35.9	9	< 2	18	6	2	209	31	8
India	Mussoorie	Low	25.0	79	8	56	25	5	1 672	26	117
Jordan	El Hassa	Medium	31.7	5	4	127	2	3	48	54	81
Mali	Tilemsi	Medium	28.8	11	8	23	20	5	20	123	52
Morocco	Khouribga	Medium	33.4	13	3	188	2	4	566	82	106
Niger	Parc W	Low	33.5	4	< 2	49	8	< 2	99	65	6
Peru	Sechura	High	29.3	30	11	128	8	5	118	47	54
Senegal	Taiba	Low	36.9	4	87	140	2	5	270	64	237
Syrian Arab Republic	Khneifiss	Medium	31.9	4	3	105	3	5	28	75	140
Togo	Hahotoe	Low	36.5	14	48	101	8	5	129	77	60
Tunisia	Gafsa	High	29.2	5	34	144	4	9	144	12	27
United Republic of Tanzania	Minjingu	High	28.6	8	1	16	2	3	40	390	42
United States of America	Central Florida	Medium	31.0	6	6	37	9	3	371	59	63
United States of America	North Carolina	High	29.9	13	33	129	3	5	146	41	19
Venezuela	Riecito	Low	27.9	4	4	33	< 2	2	60	51	32

Source: Van Kauwenbergh, 1997.

PR is the basic raw material used in the production of phosphate fertilizers. In the mineral form, it contains a wide range of both useful and potentially harmful elements that may persist through the manufacturing process. Generally, PR of sedimentary origin, which constitutes about 85 percent of world reserves, contain higher concentrations of these elements.

All PRs contain hazardous elements including undesired heavy metals, e.g. Cd, Cr, Hg, Pb, and radioactive elements, e.g. U, that are considered to be toxic to human and animal health (FAO, 2004b). The amounts of these hazardous elements vary widely among PR sources and even in the same deposit. Table 44 shows the results of a chemical analysis of potentially hazardous elements in some sedimentary PR samples. Ranges in the concentration of potentially useful and harmful elements in PRs have also been summarized in Table 45.

TABLE 45
Range in concentration of potentially useful and harmful elements in phosphate rock

Potentially useful elements	Range of concentration (mg/kg P)	Potentially harmful elements	Range of concentration (mg/kg P)
Cobalt	5–42	Arsenic	30–150
Copper	104–756	Cadmium	0.9–600
Manganese	50–2 500	Chromium	6–4 600
Molybdenum	20–70	Lead	7–180
Nickel	11–590	Mercury	0.2–12
Selenium	15–213	Thorium	28–1 528
Zinc	35–6 040	Uranium	49–1 100
		Vanadium	25–5 660

Source: Laegreid, Bockman and Kaarstad, 1999.

Undesirable heavy metals can also originate from finished fertilizers and organic manures (Table 46).

Many studies have been conducted on the potentially harmful effects of these incidental additions of elements in the diets of humans and animals and have concluded that they pose no danger, perhaps with the exceptions of Cd and the radioactive elements thorium (Th) and U.

TABLE 46
Total content of undesirable heavy metals in some fertilizers and manures

Fertilizer/manure	Cd	Cr	Pb
		(mg/kg)	
Urea	< 0.1	< 3	< 3
Triple superphosphate	9	92	3
Potassium chloride	< 0.1	< 3	3
Cow manure	1	56	16
Sewage sludge	5	350	90

Source: Webber and Singh, 1995.

Cadmium

Among the hazardous heavy metals in PRs and finished P fertilizers, Cd is probably the most researched and of greatest concern. This is because of its potentially high toxicity to human health from consuming foods derived from crops fertilized with P fertilizers containing a significant amount of Cd. In addition to Cd being added mostly through phosphatic fertilizers, significant additions to agriculture can be made through animal manures, sewage sludge and industrial effluents (Table 46). The Cd added to soil is bound strongly to soil particles and its availability to plants increases with decreasing pH. Similarly, Cd availability increases with decreasing SOM. Both high soil moisture and salinity increase Cd availability to plants, whereas high Zn concentrations decrease Cd uptake. Leafy vegetables accumulate more Cd than other food crops.

Cd ingested by animals and humans accumulates in the kidneys, where it may result in the organ dysfunction. It is recommended that the daily intake of Cd by humans should not exceed 40 µg, of which less than 5 percent is absorbed by the body. Various countries have either voluntary or mandated concentrations of Cd in fertilizers, and these are constantly under review. The reactivity of the PR influences the availability of Cd to the plant. Thus, a PR with a higher reactivity and Cd content can release more Cd than one with a lower reactivity and/or low Cd content for plant uptake. In addition to PR reactivity and Cd content, plant uptake of Cd also depends on soil pH and crop species.

Fluorine

Most PRs also have high concentrations of fluorine (F), which is a part of the apatite minerals. Fluorine content often exceeds 3 percent by weight (250 g F/kg P). Excessive F absorption has been implicated in causing injury to grazing stock through fluorosis. However, the concentrations of F in herbage were generally found to be less than 10 mg F/kg and it was concluded that plant uptake of F is unlikely to lead to problems for grazing animals in most soils. However, caution is needed in case of ingestion of soil by animals or ingestion of fertilizer material. Thus, there is a need to monitor the F additions through PRs to acid soils on a long-term basis (FAO, 2004b).

Radioactive elements

Th and U have higher concentrations in many PRs than in soil. Some PR sources may also contain a significant amount of radioactive elements compared with others, e.g. 390 mg U/kg in Minjingu PR (the United Republic of Tanzania) versus 12 mg U/kg in Gafsa PR (Tunisia). As Minjingu PR is highly reactive and agro-economically suitable for direct application to acid soils for crop production, there can be concern over the safety of using it.

K contains 0.012-percent radioactive isotope potassium-40 (^{40}K), which is constantly decaying. The addition of ^{40}K through fertilizers replaces this decaying material. The ^{40}K contained in K fertilizers may be considered undesirable and it needs to be monitored. Theoretically, application of 20 kg K/ha mixed into the top 10 cm of soil adds about 0.16 percent K annually. However, analyses of soil samples from long-term experiments where K fertilizers have been applied have detected only slight or no accumulation of these radioactive elements. In none of the experiments were there detectable increases in the concentration of these elements in the plant material.

MINIMIZING THE NEGATIVE ENVIRONMENTAL EFFECT OF NUTRIENT USE

Improving fertilizer-use efficiency

The negative effects of plant nutrients on the environment are mainly the result of undesirable losses of N through various means and losses of P through surface runoff and soil erosion. The nutrients thus lost enter the atmosphere (in the case of N) and waterbodies (in the cases of N and P). Most of such losses can be reduced by management practices that minimize the negative effects on the environment. These negative effects are not caused by any fundamental properties of these elements but as a result of their interaction with soils and plants under human intervention. Where such losses are small, the negative effects on the environment are also minimal.

N losses can be reduced significantly by adopting practices that improve N utilization by crops and N conservation in the soil. Towards this goal, the integrated management of N with water and balanced nutrient application are of utmost importance for increasing nitrogen-use efficiency. This requires that N application rates not be excessively above the optimum whether delivered through mineral fertilizers or organic manures. In the case of P, appropriate soil and water conservation measures, application rates based on soil P levels and best methods of application are very important.

The practices that can lead to improved nitrogen-use efficiency are listed below. These are also practices that will reduce N losses as efficiency and losses are inversely related:

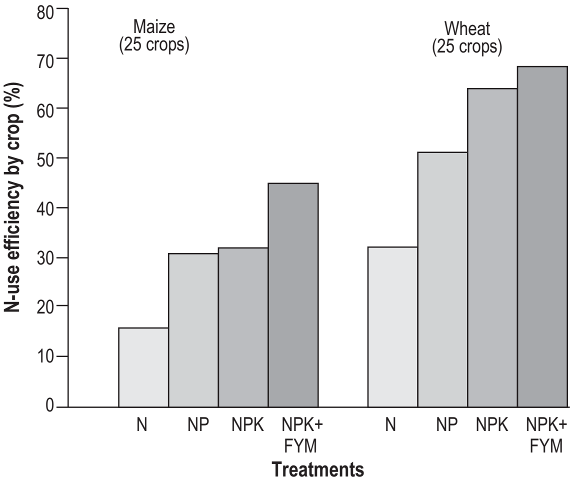
- Matching N application rates with the nature and yield potential of the crop.
- Ensuring a good crop stand and optimal plant population.
- Correcting all nutrient deficiencies in order to provide balanced nutrition.
- Distributing of total N to be applied in splits of 25–40 kg N/ha during crop growth.
- Increasing the number of splits in coarse-textured soils and high rates of N.
- Increasing the number of splits in the case of long-duration varieties.

- ➢ Synchronizing N application with moisture availability either through rainfall or irrigation.
- ➢ Using nitrification inhibitors where economical and feasible with N fertilizers.
- ➢ Avoiding overirrigation.
- ➢ Withholding N application during attacks by pests and diseases.
- ➢ Applying pre-plant N below the soil surface for dryland crops raised on stored soil moisture.
- ➢ Minimizing surface application of urea and ammonia fertilizers to alkaline soils.
- ➢ Deep placement of supergranules in flooded-rice fields.
- ➢ Minimizing nitrate fertilizers to flooded-rice soils.
- ➢ Following INM practices, e.g. combined application of mineral fertilizers with organic/green manures.
- ➢ Preferring S-containing N sources in soils that are also deficient in S.
- ➢ Adopting conservation tillage and residue recycling to control surface runoff and promote infiltration.
- ➢ Using organic manures to improve infiltration and enhance WHC.

Advances in agricultural technologies (e.g. improved soil sampling and analysis, better plant diagnostic methods, less soil-degrading tillage methods, use of starter fertilizers, and better timing and placement of nutrients) now enable farmers to apply nutrients with greater accuracy, minimizing or avoiding altogether any damage to soil, water, and air. For example, maize farmers in the United States of America increased yields by 40 percent and nitrogen-use efficiency by 35 percent between 1980 and 2000. One of the factors that made this possible was balanced nutrient application and correction of nutrient deficiencies.

FIGURE 51

Impact of balanced and integrated nutrient management on the nitrogen-use efficiency by maize and wheat in an alluvial soil in Punjab, India



Source: Brar and Pasricha, 1998.

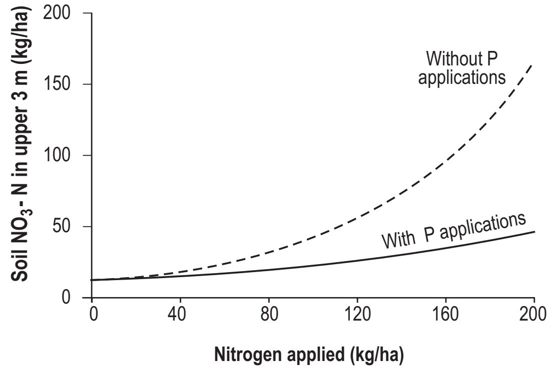
It is known that nitrogen-use efficiency declines markedly where P, K or any other nutrient needed is omitted from the fertilization programme. This is demonstrated in Figure 51 and Table 27.

Balanced fertilization can have dramatic effects on soil NO_3-N concentrations, as shown by a study in Kansas, the United States of America (Figure 52). Where N was applied without P, there was a dramatic and dangerous accumulation of NO_3^- in the soil profile. Where N was applied with P, the accumulation was low and within the range useful to plants. In the intensively fertilized region of Punjab, India, balanced nutrient application significantly reduced the amount of N in the rootzone after harvest. When only N was applied to wheat or maize, a substantial portion of it was found as nitrate N in the soil up to 2 m depth. However, when 60 kg P_2O_5 and 30 kg K_2O/ha were also applied along with 120 kg N/ha, there was little nitrate N that could potentially leach below the rootzone. Moreover, as the irrigation rate was increased but its frequency decreased, more nitrate N leached to deeper soil layers (Singh, 1996).

In addition to minimizing negative environmental effects, the efficient use of applied nutrients has another very important payoff in terms of reducing the amounts of nutrients required to achieve a given production goal. An analysis of nutrient requirement in Asia shows that with low fertilizer efficiency and associated innovations, developing Asia will be able to meet the minimum cereal yield requirement in 2010 (3.5 tonnes/ha) with 230 kg/ha of nutrients from fertilizers and in 2030 (5.5 tonnes/ha) with 475 kg/ha of nutrients from fertilizers. With high fertilizer efficiency and associated innovations, the corresponding nutrient requirements for the stated yields in 2010 and 2030 would be 160 kg/ha and 380 kg/ha of nutrients from fertilizers (FAO, 1993b). Therefore, the efforts of agricultural research and extension services, emphasizing fertilizer efficiency at farm level, can probably lead to a saving of 70 kg/ha ($N + P_2O_5 + K_2O$) by 2010 and 95 kg/ha by 2030 (Figure 53).

FIGURE 52

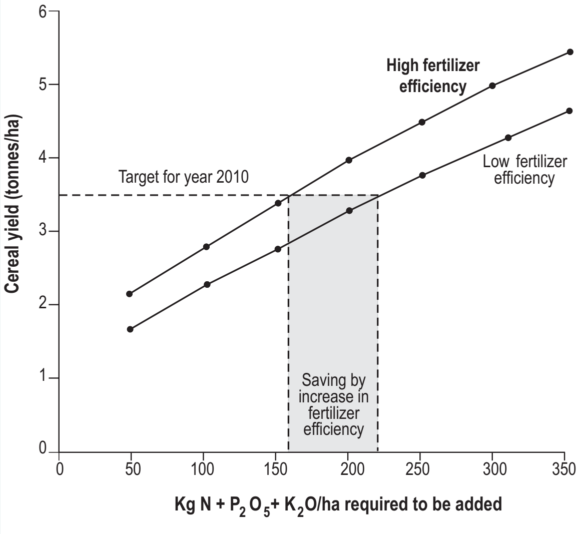
Impact of balanced fertilization on soil NO_3-N concentrations in Kansas, the United States of America



Source: Stewart, 2002.

FIGURE 53

Importance of efficient fertilizer use in achieving required cereal yield levels in Asia



Source: FAO, 1993b.

Managing nutrients to minimize losses

Efficient use of fertilizers and manures ensure that minimum amounts are left to be lost permanently from a site. Developments of nutrient budgets are the most practical way of preventing losses of nutrients to the environment. This, together with an understanding of the loss processes, can help to reduce losses to an environmentally acceptable level or even eliminate them. Table 47 summarizes the conditions favouring N losses and general strategies for minimizing them. Some guidelines for minimizing N losses are also provided in Table 43.

Losses of P to the environment can be reduced by: (i) avoiding excessive application rates of animal manures and slurries; (ii) soil and water conservation measures to reduce surface runoff and soil erosion; and (iii) balanced nutrient application to enhance crop utilization of available P.

TABLE 47
Conditions favouring N losses and general strategies for minimizing such losses

Channel of N loss	Conditions that favour loss of N	Strategies for minimizing N loss
Volatilization	Sandy soils	Mix fertilizers with soil
(loss as ammonia)	Ammonium or urea fertilizer left on soil surface	Drill basal dose for upland crops, follow N broadcast by hoeing, light irrigation. etc.
	Alkaline soils/over liming	Use gypsum, pyrite and organic manure
	Shallow N application in flooded-rice soils	Practice split application of N
	Hot dry period	Use USGs in medium–fine textured soils (deep placement in rice)
Leaching	Sandy soils	Add organic matter
(loss of N from rootzone with drainage water)	High rainfall areas	Split application of N (more splits at higher rates of N)
	Heavily irrigated fields (more water/irrigation)	Controlled/light irrigations (less water per irrigation)
	Heavy N applications or all N as basal	More splits of N for long duration crops/ varieties and in high rainfall areas
	Unbalanced fertilizer application leading to poor utilization of N	Balanced fertilization to ensure better utilization of applied N fertilizer
		Use soil-cured urea or neem coated urea
Denitrification	Conditions favouring movement of nitrate into lower depths, compact pockets	Improve drainage and soil aeration, avoid soil compaction
(Gaseous loss owing to biological or chemical decomposition of nitrate)	Waterlogged soils, poor soil aeration	Adopt practices to conserve N in ammonium form in reduced soils (flooded rice)
	Addition of nitrate N to waterlogged soils	Use non-nitrate sources for basal application
	Surface application of N to flooded rice soils	Place USG or NH_4-N 10–15 cm deep in flooded-rice soils
	High temperature	
	Acidic pH (for chemical denitrification), non-acidic condition (for biological denitrification)	Lime acid soils
Erosion/runoff	Sloping lands	Contour cultivation
(loss of N through surface flow due to heavy rains, over irrigation or soil erosion)		Land levelling
	Lack of soil cover	Minimum/zero tillage
	Poorly levelled fields	Suitable moisture conservation practices (ploughing before rain, bunding, mulching etc.)
	High level of tillage	Incorporate fertilizer in soil
	Inadequate moisture conservation	Controlled and light irrigations

Guidelines for the best agricultural practices to optimize fertilizer use in Asia and the Pacific were developed several years ago (FADINAP, 1993). Similar practices for Europe are also available (IFA/EFMA, 1998). The objectives of these guidelines are:

- to integrate the principles of economic crop production with environmental protection;
- to create public confidence that farmers use fertilizers responsibly;
- to provide planners and policy-makers with a sound understanding of the role of fertilizer in sustainable systems of crop production.

The need for widespread dissemination and adoption of best agricultural practices cannot be overemphasized. When this happens, nutrient management will be based on scientific findings, it will be efficient, profitable and associated with minimum adverse effect on the environment, a concern common to all sources of nutrients be they mineral fertilizers or organic manures.

Glossary

Acid-forming fertilizer

A fertilizer that leaves behind an acidic effect in the soil (reduces soil pH). Such fertilizers, which lack a metallic cation, are generally acid forming. Their continuous use makes a soil acid (lowers pH) and reduces soil quality and, hence, productivity. The excess acidity can be neutralized by lime application. This is generally of practical importance in the case of nitrogenous fertilizers. Examples: ammonium sulphate, ammonium chloride, anhydrous ammonia and urea.

Agricultural liming material

Material containing oxides, hydroxides and/or carbonates of Ca and/or Mg, used for neutralizing the acidity of the soil. Its use is referred to as liming.

Alkaline (or basic) fertilizer

A fertilizer that leaves behind an alkaline reaction in the soil (raises soil pH). Examples: calcium nitrate, sodium nitrate. Opposite of acid-forming fertilizer.

Ammoniated superphosphate

A product obtained from superphosphate treated with ammonia or solutions containing free ammonia. The end product provides extra N but, in the process, its total P content and also the water solubility of this P are reduced.

Ammonium chloride (sal ammonia or muriate of ammonia)

Ammonium salt of hydrochloric acid containing 25 percent N in ammoniacal form. Formula: NH4Cl. An acid-forming fertilizer.

Ammonium citrate

A compound, the solution of which is used to determine the available phosphate content of fertilizers usually consisting of water-soluble and citrate-soluble phosphate.

Ammonium molybdate

An important molybdenum fertilizer containing 52–54 percent Mo. Formula: $(NH_4)_6Mo_7O_{24}\ .4H_2O$. It can be applied either to soils and seeds, or through foliar spray. Standard specifications of ammonium molybdate based on Indian experience are:

- molybdenum (as Mo), percent by weight, minimum: 52.0;
- matter insoluble in water, percent by weight, maximum: 1.0;
- lead (as Pb), percent by weight, maximum: 0.003.

Ammonium nitrate

A product obtained by neutralizing nitric acid with ammonia. Formula: NH_4NO_3. It is usually in a granular or prilled form, and coated with a suitable material to prevent absorption of moisture and caking in storage. Fertilizer-grade ammonium nitrate has a total N content of 33–34.5 percent, of which 50 percent is present as ammoniacal-N and 50 percent as nitrate-N. It leaves behind an acidic effect in the soil.

Ammonium phosphate

Group of solid fertilizers, manufactured by reacting ammonia with phosphoric acid. Type of compound formed depends on the amount of ammonia that is reacted with phosphoric acid. Two important ammonium phosphates are: (i) mono-ammonium phosphate or MAP ($NH_4H_2PO_4$), containing about 11 percent N and 52 percent P_2O_5; and (ii) di-ammonium phosphate or DAP [$(NH_4)_2HPO_4$], typically containing 18 percent N and 46 percent P_2O_5.

Ammonium phosphate sulphate

An important complex fertilizer containing N, P and S. Typical grades are 16-20–0–15 percent and 20–20–0–15 percent in terms of N + P_2O_5 + K_2O + S. It is essentially a factory-made complex consisting of 60 percent ammonium sulphate and 40 percent ammonium phosphate. Useful for basal dressing to provide N, P and S, all of which are present in water-soluble, plant available form.

Ammonium sulphate (AS)

Traditionally, the best-known N and S fertilizer. Formula: $NH_4(SO_4)_2$. It contains about 21 percent N (all as ammonium) and 23–24 percent S (all as sulphate). Its specific gravity is 1.769, its bulk density is 720–1 040 kg/m³ and its angle of repose is 32–33 °. It is an acid-forming fertilizer because it lacks a metal cation. Highly soluble in water, it can be produced through various processes and used directly or as an ingredient of fertilizer mixtures. It is used as part of the basal dressing or as top-dressing to provide both N and S. Ammonium sulphate should not be mixed with PR or urea.

$$\underset{\text{Ammonia Sulphuric acid}}{2NH_3 + H_2SO_4} \longrightarrow \underset{\text{Ammonium sulphate}}{2(NH_4)_2SO_4}$$

Standard specifications of ammonium sulphate based on Indian experience are:

- moisture, percent by weight, maximum: 1.0;
- ammoniacal-N, percent by weight, minimum: 20.6;
- sulphur (as S), percent by weight, minimum: 23.0;
- free acidity (as H_2SO_4), percent by weight, maximum (0.04 for material obtained from by-product ammonia and by-product gypsum): 0.025;
- arsenic (as As_2O_3), percent by weight, maximum: 0.01.

Ammonium sulphate nitrate (ASN)

A fertilizer containing 26 percent N and 15 percent S, both in soluble and plant available form. It is a double salt of ammonium sulphate and ammonium nitrate in which 75 percent of total N is present as ammoniacal-N and 25 percent as nitrate-N. Agronomically, it is comparable to ammonium sulphate, except for the more mobile nitrate-N component in ASN.

Ammonium thiosulphate

A liquid fertilizer containing 12 percent N and 26 percent S (thio refers to S). Fifty percent of the S is in the sulphate form and the rest is in elemental form. It can be used directly or mixed with neutral to slightly acid P-containing solutions or aqueous ammonia or N solutions to prepare a variety of NPK + S and NPKS + micronutrient formulations. It can also be applied through irrigation, particularly through drip and sprinkler irrigation.

Aqueous ammonia

A solution containing water and ammonia in any proportion, usually qualified by a reference to ammonia vapour pressure. For example, aqua ammonia has a pressure of less than 0.7 kg/cm^2. Commercial grades commonly contain 20–25 percent N. It is used either for direct application to the soil or for preparation of ammoniated superphosphate.

Apatite

Common name of the major P-bearing compound in PR (used as raw material in the manufacture of phosphate fertilizers). General formula: $Ca_{10}(PO_4, CO_3)_6(F, OH, Cl)_2$. Depending on the dominance of F, Cl or OH in the apatite crystal structure, it is known as fluorapatite, chlorapatite or hydroxyapatite.

Ash

The mineral residue remaining after the destruction of organic material by burning. Ash of plant residues or wood is usually a rich source of K.

Azolla

A floating freshwater fern. It fixes N in symbiotic association with the cyanobacterium (BGA) *Anabaena azollae*. Cultivation of *Azolla* in Viet Nam and China began during the Ming dynasty (1368–1644). *Azolla* is distributed in both temperate and tropical rice-growing regions. One crop of *Azolla* can provide 20–40 kg N/ha to the rice crop in about 20–25 days.

Benefit–cost ratio (BCR)

The ratio of the value of extra crop produced (minus cost of fertilizer or any other production input) to the cost of fertilizer. It indicates the rate of net returns from the use of an input and, hence, is an important indicator of the degree of profitability from input use. If a fertilizer costing US$50 produces extra crops worth US$150, then the BCR = (150 - 50)/50 = 2. A useful decision-making tool before investing in an input. BCR = VCR - 1.

Biofertilizer

A rather broad term used for products (carrier- or liquid-based) containing living or dormant micro-organisms like bacteria, fungi, actinomycetes and algae alone or in combination, which on application help in fixing atmospheric N or solubilize/mobilize soil nutrients in addition to secretion of growth-promoting substances for enhancing crop growth. “Bio” means living, and “fertilizer” means a product that provides nutrients in usable form. Biofertilizers are also known as bioinoculants or microbial cultures. Strictly speaking, the term is a misnomer, albeit a widely used one. Unlike fertilizers, these are not used to provide nutrients present in them, except *Azolla* where used as green manure. Biofertilizers can be broadly classified into four categories:

- N-fixing biofertilizers: Rhizobium, Azotobacter, Azospirillum, Acetobacter, BGA and Azolla;
- P-solubilizing/mobilizing biofertilizers (PSB or PSM): P-solubilizing, e.g. *Bacillus*, *Pseudomonas* and *Aspergillus*, P-mobilizing, e.g. VAM;
- composting accelerators: (i) cellulolytic (*Trichoderma*), and (ii) lignolytic (*Humicola*);
- plant-growth promoting rhizobacteria: species of *Pseudomonas*.

Bioinoculant

A biological preparation containing living organisms, such as biofertilizers, used in agriculture for inoculation of seeds, soils or other plant materials. See biofertilizer.

Biological nitrogen fixation (BNF)

The process involving the conversion of nitrogen gas (N_2) into ammonia through a biological process (in contrast to industrial N fixation). Same as biological dinitrogen fixation. Many micro-organisms, such as *Rhizobium*, *Azotobacter* and BGA utilize molecular N_2 through the help of nitrogenase enzyme and reduce it to NH_3:

$$N_2 + 6H^+ + 6e^- \longrightarrow 2NH_3$$

It is a major source of fixed N for plant life on the earth. Estimates of global terrestrial BNF range from 100 to 290 million tonnes of N per year, of which 40–48 million tonnes is estimated to be biologically fixed in agricultural crops and fields. Mo and Co are considered to play a particularly important role in BNF.

Blue green algae (BGA)

Photosynthetic, N-fixing algae, also known as cyanobacteria. These are unicellular and aerobic organisms. Their role in paddy-fields was reported by P.K. Dey of India in 1939. More than 100 species of BGA are known to fix N. Commonly occurring BGA are *Nostoc*, *Anabaena*, *Aulosira*, *Tolypothrix*, and

Calothrix. These are used as biofertilizer for wetland rice (paddy) and can provide 25–30 kg N/ha. They also secrete hormones such as IAA and GA and improve soil structure by producing polysaccharides, which help in the binding of soil particles resulting in better soil aggregation. Also used as a soil conditioner and to prevent soil erosion through mat formation.

Borax

Sodium tetraborate compound. Formula: $Na_2B_4O_7.10H_2O$. Contains 10.5 percent B. An important B fertilizer for soil or foliar application. Standard specifications of borax based on Indian experience are:

- content of boron (as B), percent by weight, minimum: 10.5;
- matter insoluble in water, percent by weight, maximum: 1.0;
- pH: 9.0–9.5;
- lead (as Pb), percent by weight, maximum: 0.003.

Bulk density

Mass per unit bulk volume (including pores) of soil or particle that has been dried to constant weight at 105 °C. The bulk density of different biofertilizer carriers is: peat (1.02 g/cm^3), lignite (1.08 g/cm^3), and charcoal (0.43 g/cm^3). The bulk density of ammonium sulphate is 720–1 040 kg/m^3.

Bulk fertilizer

Commercial fertilizer in a non-packed form.

Cadmium (Cd)

A toxic heavy metal. Atomic weight: 112.4. Usual content in soils is 0.4 ppm. Can enter finished fertilizers through PR, which is an important raw material, and other sources. Potentially toxic to plants and animals. Of great concern to human health, Cd is associated with crippling condition known as *Itai-itai* (Japanese). PRs can contain a wide range of Cd content. See phosphate rock.

Caking

Refers to the change of fertilizer powder or granules into hard lumps. This is usually a consequence of extended storage under pressure in a humid environment. It is a sign of deterioration in physical quality. Use of anti-caking agents can help to minimize caking.

Calcium ammonium nitrate (CAN)

A mixture of ammonium nitrate and finely pulverized limestone or dolomite, granulated together. It contains 21–26 percent N, half in the form of ammoniacal-N and half in the form of nitrate-N. Its use does not make the soil acid by virtue of the Ca in it. Standard specifications of CAN based on Indian experience are:

- moisture, percent by weight, maximum: 1.0;
- total ammoniacal- and nitrate-N, percent by weight, minimum: 25.0;

- ammoniacal-N, percent by weight, minimum: 12.5;
- calcium nitrate, percent by weight, maximum: 0.5;
- particle size: not less than 80 percent of the material shall pass through 4-mm IS sieve and be retained on 1-mm IS sieve. Not more than 10 percent of the material shall be below 1-mm IS sieve.

Cation exchange capacity (CEC)

The capacity of a soil or any other substance with negatively charged exchange complex to hold cations in exchangeable form is referred as the CEC. It is a measure of the net negative charge of a soil. Expressed in me/100 g of soil (old term) or Cmol/kg (new term). The CEC depends on the type and proportion of organic matter and clay minerals present in the soil. Clay soils have a higher CEC than sandy soils.

Citric-acid-soluble P_2O_5

That part of the total P_2O_5 particularly in basic slag and bone meal that is insoluble in water but soluble in 2-percent citric acid solution and considered to be plant available.

Clay

A group of hydrated aluminium silicates of microcrystalline structure. A common constituent of soils. Smallest size particles of mineral matter in the soil, usually less than 0.002 mm in diameter. Clays play a major role in determining soil texture, soil structure, water retention, CEC and nutrient dynamics. Examples: kaolinite, illite and montmorillonite.

Coated fertilizer

A fertilizer whose granules are covered with a thin layer of a different material in order to improve its behaviour and/or modify the characteristics of the fertilizer. Commonly done to improve the physical condition of a fertilizer or reduce the rate of release of nutrients in the soil after application.

Complex fertilizer

A fertilizer that contains two or more major nutrients (N, phosphate and potash) made by a chemical reaction between the nutrient-containing raw materials. Same as multinutrient fertilizer. Examples: NP complex 23–23–0, and NPK complex 12–32–16.

Compost

An organic manure or fertilizer produced as a result of aerobic, anaerobic or partially aerobic decomposition of a wide variety of crop, animal, human and industrial wastes. Conveniently categorized as rural or urban (town) compost according to the type and location of wastes used for composting. Compost prepared with the aid of earthworms is referred to as vermicompost. Typical nutrient content of rural compost is 0.5 percent N, 0.2 percent P_2O_5 and 0.5 percent K_2O, while that of urban compost is 1.5 percent N, 1.0 percent P_2O_5 and 1.5 percent K_2O. On average, compost also contains 10 ppm Zn, 6 ppm B and 12 ppm Mn. Nutrient status of a compost depends largely on the nutrient content of the wastes composted.

Compound fertilizer

A fertilizer having a declarable content of at least two of the nutrients N, P and K, obtained chemically (as in complex fertilizers), by mixing (as in fertilizer mixtures/ bulk blends), or both.

Copper sulphate

Most common Cu fertilizer. Formula: $CuSO_4.5H_2O$ (24 percent Cu). It comes in particle sizes varying from fine powder to granular. A less hydrated form, $CuSO_4.H_2O$, contains 35 percent Cu. Standard specifications of $CuSO_4.5H_2O$ based on Indian experience are:

- copper (as Cu), percent by weight, minimum: 24.0;
- sulphur (as S), percent by weight, minimum: 12.0;
- matter insoluble in water, percent by weight, maximum: 1.0;
- soluble iron and aluminium compounds (expressed as Fe), percent by weight, maximum: 0.5;
- lead (as Pb), percent by weight, maximum: 0.003;
- pH: not less than 3.0.

Critical level (CL)

That level of concentration of a nutrient in the plant or available nutrient in the soil that is likely to result in 90 percent of the maximum yield. Where the CL is determined correctly, the probability of crop response to applied nutrient is high at below the CL and low above the CL. Same as critical limit. Used as a diagnostic tool in decision-making for nutrient application.

Critical relative humidity (CRH)

The relative humidity (usually stated at 30 °C) at which a material (fertilizer) starts absorbing moisture from the air. CRH in case of micronutrient fertilizers has not received much attention. The lower the CRH of a fertilizer, the more hygroscopic it is. Such materials need special care during storage. Some values of CRH at 30 °C are:

- urea: 75.2;
- ammonium sulphate: 79.2;
- MOP: 84.0;
- sulphate of potash: 96.3;
- DAP: 82.5.

Cyanobacteria

BGA are known also as cyanobacteria as they are procaryotic-like bacteria and their cells contain phycocyanine (blue) and green pigment. They are divided into four groups:

- unicellular, reproduced by binary fission or budding (e.g. *Gleocapsa*);
- unicellular, reproduced by multiple fission (e.g. *Chloroecidiopsis*);
- filamentous, non-heterocystous (e.g. *Plectonema*);
- filamentous, heterocystous (e.g. *Nostoc*).

Deficiency

Refers to inadequacy. In soils and plants, the state of inadequate supply or low availability of an essential nutrient for optimal plant growth. In quantitative terms, the nutrient status is below the critical level. This can be corrected by external nutrient application through fertilizers and manures. Deficiency symptoms refer to visible signs of the deficiency of a nutrient element in a growing plant or its produce, usually visible to the naked eye. Some common descriptors of nutrient deficiency symptoms in growing plants are:

- bronzing: development of bronze/copper colour on the tissue;
- chlorosis: loss of chlorophyll, resulting in loss of green colour, paleness, appearance of yellow tissue;
- decline: onset of general weakness as indicated by loss of vigour, poor growth and low productivity;
- dieback: collapse of the growing tip, affecting the youngest leaves;
- firing: burning of tissue accompanied with dark brown or reddish-brown colour;
- lesion: a localized wound of the tissue accompanied by loss of normal colour;
- necrosis: death of tissue;
- scorching: burning of the tissue accompanied by light brown coloration (this can also result from faulty spraying, salt injury, etc.).

Dicalcium phosphate

A product containing not less than 34 percent P_2O_5 in citrate-soluble form, which is considered available to plants. Formula: $CaHPO_4$.

Dolomite

An Mg-containing natural limestone mineral used for liming acid soils that also need Mg application. Formula: $CaMg(CO_3)_2$. Contains 40–45 percent CaO and 5–20 percent MgO. An important soil amendment.

Dung

The semi-solid excreta of large animals (excluding humans). Used as a manure, soil conditioner, biogas plant input and as domestic fuel. Dung is the main ingredient of FYM.

Equivalent acidity

Refers to parts by weight of calcium carbonate (as $CaCO_3$) required to neutralize the acidity resulting from the use of 100 parts by weight of an acid-forming fertilizer. The equivalent acidity of some common fertilizers is:

- anhydrous ammonia: 148;
- ammonium chloride: 128;
- ammonium sulphate: 110;
- ammonium nitrate sulphate: 93;
- urea: 84;
- DAP: 74;
- MAP: 65;
- ammonium nitrate: 63.

Equivalent basicity

The number of parts by weight of calcium carbonate (as $CaCO_3$) that corresponds in acid neutralizing capacity of 100 parts by weight of the fertilizer. In other words, it shows the neutralizing capacity, expressed as kilograms of $CaCO_3$ per 100 kg of the fertilizer. The equivalent basicity of some common fertilizers is:

- calcium nitrate: 21;
- dicalcium phosphate: 25;
- sodium nitrate: 29.

Farmyard manure (FYM)

Bulky organic manure resulting from naturally decomposed mixture of dung and urine of farm animals along with the litter (bedding material). Average, well-rotted FYM contains 0.5–1.0 percent N, 0.15–0.20 percent P_2O_5 and 0.5–0.6 percent K_2O. Desired C:N ratio in FYM should not exceed 15–20:1. In addition to NPK, it may contain about 1 500 ppm Fe, 7 ppm Mn, 5 ppm B, 20 ppm Mo, 10 ppm Co, 2 800 ppm Al, 12 ppm Cr and up to 120 ppm Pb. Often fully or partially air-dry dung is used as FYM. See bulky organic manure.

Ferrous sulphate

A common Fe fertilizer. Formula: $FeSO_4.7H_2O$. Contains 19 percent Fe and 11 percent S. Same as iron sulphate. Standard specifications of ferrous sulphate ($FeSO_4.7H_2O$) based on Indian experience are:

- ferrous iron (as Fe), percent by weight, minimum: 19.0;
- sulphur (as S), percent by weight, minimum: 10.5;
- free acid (as H_2SO_4), percent by weight, maximum: 1.0;
- ferric iron (as Fe), percent by weight, maximum: 0.5;
- matter insoluble in water, percent by weight, maximum: 1.0;
- pH: not less than 3.5;
- lead (as Pb), percent by weight, maximum: 0.003.

Fertigation

The practice of applying fertilizers together with irrigation water and not in a separate operation. More often advocated for use with drip irrigation systems than with conventional flood irrigation. In principle, all required nutrients including micronutrients can be applied through fertigation. Products available for drip irrigation should be highly water soluble and include products containing major nutrients, micronutrient salts as well as chelates of EDTA and EDDHA. Similar to chemigation.

Fertilization

The practice of applying fertilizers for plant nutrition. The fertilizers can be applied through soil, irrigation water or sprayed on plant leaves. Same as fertilizer application.

Fertilizer

A mined, refined or manufactured product containing one or more essential plant nutrients in available or potentially available forms and in commercially valuable amounts without carrying any harmful substance above permissible limits. Although organic fertilizers are also being prepared and used, they are not yet covered by the term fertilizers, largely due to tradition. Same as mineral or inorganic fertilizer. Examples: urea, SSP, zinc sulphate, borax, and copper sulphate.

Fertilizer grade

An expression used in extension and the fertilizer trade referring to the legal guarantee of the available plant nutrients expressed as a percentage by weight in a fertilizer, e.g. a 12–32–16 grade of fertilizer indicates 12 percent N, 32 percent P_2O_5 and 16 percent K_2O in that complex fertilizer.

Fertilizer mixture

A mixture prepared by physically mixing two or more finished fertilizers so as to contain two or more out of N, P and K plus any other nutrients. Mixture can be powdery or granulated. Examples: multimicronutrient mixtures, NPK mixtures, and bulk blends.

Fertilizer placement

A method of fertilizer application in which the fertilizer is placed at a specific point or zone on or below the soil surface. It minimizes soil–fertilizer contact and creates higher nutrient concentration near the point of placement than in the general field. Examples: placement in holes around tea bushes, deep placement of USGs between rice hills, and drilling of phosphatic fertilizer below the seed.

Fertilizer quality

Chemical and physical state of a finished fertilizer as specified in the accepted quality standards of a country. For example, in India, fertilizer quality should be as per the Fertilizer Control Order (FCO). Quality can be acceptable (good) or substandard (non-standard), in which case it deviates from the stated parameters. Fertilizer loses its quality when it is non-standard and/or adulterated. Fertilizer quality control refers to totality of all legislation, enforcement, testing and monitoring activities aimed at ensuring its quality as laid down in quality standards.

Filler

Any material mixed with fertilizers during production for purposes other than addition of plant nutrients so as to give anti-caking properties and for adjusting their weight to bring the percentage of nutrients so as to maintain grade composition. Must not contain any harmful or toxic substance. Examples: sand, lime, dolomite, silica, and sawdust.

Fortified fertilizer

A fertilizer to which another compound has been deliberately added in order to enhance its nutrient value. Several common fertilizers can be fortified with compounds of nutrients, such as S, B and Mo. An additional advantage of fortification is that small amounts of micronutrients needed can be applied uniformly over a field with ease. Examples: SSP fortified with B (boronated SSP), urea fortified with Zn (zincated urea), and NP/NPK complexes fortified with B or Zn.

Fused calcium and magnesium phosphate

A product derived from the fusion of PR with about 30 percent of magnesium oxide as such or as a mineral silicate. Typical fused calcium phosphate contains 27 percent P_2O_5 and 19 percent Ca while fused magnesium phosphate contains 8 percent Mg and 10 percent P_2O_5. Most of the phosphate is in citrate-soluble (available) form, although very little is water soluble. These products must be finely ground in order to be effective sources of phosphate for plants as their availability is related directly to their specific surface, which in turn is inversely proportional to their particle size.

Granular fertilizer

Solid material formed into particles of a predetermined mean size.

Granulation

Techniques using a process such as agglomeration, accretion or crushing to make a granular fertilizer.

Green manure

Refers to fresh green plant matter (usually of legumes and often specifically grown for this purpose in the main field) that is ploughed in or turned into the soil to serve as manure. Several legume plants are used as green manure crops.

These are an important source of organic matter and plant nutrients, specially N. A key component (where feasible) of integrated plant nutrition systems (IPNS). Green manure can either be grown *in situ* and incorporated or grown elsewhere and brought in for incorporation in the field to be manured. Not all plants can be used as a green manure in practical farming. Green manures may be: plants of grain legumes such as pigeon pea, green gram, and cowpea; perennial woody multipurpose legumes such as *Leucaena leucocephala* (*subabul*), *Gliricidia sepium, Cassia siamea*; and non-grain legumes, such as *Crotalaria, Sesbania, Centrosema, Stylosanthes* and *Desmodium*. As green manures add whatever they have absorbed from the soil, they also promote the recycling of soil nutrients from lower depths to the topsoil. The most desirable characteristics in selecting a green manure crop are: (i) local adaptability of the plant; (ii) fast growth and production of a large amount of green matter (biomass) per unit area per unit time; (iii) tolerance to soil and environmental stresses such as acidity, alkalinity and drought; (iv) resistance to pests; and (v) easy to decompose, requiring minimum gap between incorporation and planting the main crop.

Ground phosphate rock

Material obtained by grinding naturally occurring PR to a fineness meeting relevant specifications or accepted custom, generally for direct application to soils.

Growth medium

Any material such as soil and peat used as a support for plant roots that has a capacity for water retention and that may contain added or naturally occurring nutrients. Also a medium in which micro-organisms are grown such as during biofertilizer production.

Guano

Group of organic manures derived from animal excreta, usually of small animals and includes materials such as bat, Peruvian and fish guano. General N content of guano can be 0.4–9.0 percent and total P_2O_5 can be 12–26 percent. Found and used in certain areas only.

Gypsum

The naturally occurring mineral calcium sulphate. Formula: $CaSO_4.2H_2O$ (containing 18.6 percent S and 23 percent Ca). Agricultural grade gypsum is usually of 70-percent purity containing 13–15 percent S and 16–19 percent Ca. Its solubility in water is 2.5 g/litre. It is an important source of both Ca and S for plants and is commonly used as an amendment for reclaiming alkali soils.

Heavy metal

Elements with a high atomic weight and specific gravity of more than 5 (density greater than 500 kg/m^3). These include plant nutrients as well as potential pollutant/toxic metals to plants and animals (Pb, Cd, etc). Some P fertilizers may contain heavy metals that originate from the PR. Most metal micronutrients (Fe, Mo, Mn, Ni, Cu and Zn) are also heavy metals. Thus, not all heavy metals are toxic, especially where present within permissible limits. The toxicity of a metal depends on its concentration in relation to plant needs and tolerance. At excessive concentrations, even micronutrients can become toxic.

High-analysis fertilizer

An arbitrary term for a fertilizer containing more than 25 percent of one or more of the three major plant nutrients, namely, N, P (as P_2O_5) and K (as K_2O). Examples: urea, DAP, NPK complexes, polyphosphates, and elemental S products.

Hoof and horn meal

An organic manure obtained from the processing, drying and grinding of animal hooves and horns. Usually contains 13–15 percent N and 0.3–1.5 percent P_2O_5.

Humus

The highly decomposed fraction of SOM having little resemblance to the matter from which it has been derived. It is characterized as an amorphous, dark coloured, nearly odourless, stable material of high molecular weight. It is the major food reservoir of soil microbes as it contains organic C and N needed for their development. Humic material has a very high CEC (200–500 Cmol/kg soil). It improves the buffering and WHC of soil. The process of formation of humus is called humification.

$$\text{Organic residues} \xrightarrow{\text{microbial decomposition}} CO_2 + H_2O + \text{humus} + \text{nutrients}$$

Kieserite

Trade name for magnesium sulphate monohydrate. Formula: $MgSO_4.H_2O$ (16 percent Mg). Sparingly soluble in cold water but readily soluble in hot water. Its bulk density is 1.4 g/cm^3 and its angle of repose is 34 °. Used as fertilizer for soil or foliar application to provide Mg as well as S.

Liquid fertilizers

Fertilizers in liquid finished form. Examples: urea ammonium nitrate solutions, polyphosphates, thiosulphates, suspensions, and special formulations for fertigation. Same as fluid fertilizers. Several liquid fertilizers can contain micronutrients, which can be in solution, in chelated (sequestered) form or in suspended form using suspension agents such as special type of clay, usually 2 percent attapulgite.

Liquid manure

Liquid resulting from animal urine and litter juices or from a dung heap that can be used as an organic manure.

Liming material

Product containing one or both of the elements Ca and Mg, generally in the form of an oxide, hydroxide or carbonate, principally intended to maintain or raise the pH of soil.

Low-analysis fertilizer

An arbitrary term for a mineral fertilizer containing less than 25–30 percent (N), P (as P_2O_5) and K (as K_2O). Same as “dilute fertilizer”. Term falling into disuse for its restrictive nature and non-recognition of other useful nutrients such as S in them. Examples: ammonium sulphate and SSP.

Luxury consumption

Absorption of a nutrient by a plant well in excess of the quantities required. Common in case of N, K and Cl but can also occur in Zn. A waste from the farmer’s viewpoint as the excess nutrient absorbed does not lead to extra yield. Reduces the physiological NUE although increased crop recovery of added nutrients.

Macronutrients

Essential plant nutrients that are required by plants in relatively large amounts (as compared with micronutrients). Include: N, P, K S, Ca and Mg, as also C, H and O (non-mineral nutrients).

Magnesium sulphate

A common Mg fertilizer. In anhydrous form, $MgSO_4$ contains 20 percent Mg. In hydrated form, $MgSO_4.7H_2O$ (Epsom salt), it contains 10 percent Mg. It is readily soluble in water, has a bulk density of 1 g/cm^3 and an angle of repose of 33°. It can be used for soil application and for foliar application. See also Kieserite. Standard specifications of magnesium sulphate ($MgSO_4.7H_2O$) based on Indian experience are:

- free flowing – crystalline form;
- magnesium (as Mg), percent by weight, minimum: 9.6;
- sulphur (as S), percent by weight, minimum: 12.0;
- matter insoluble in water, percent by weight, maximum: 1.0;
- lead (as Pb), percent by weight, maximum: 0.003;
- pH (5-percent solution): 5.0–8.

Manganese sulphate

A common Mn fertilizer. Formula: $MnSO_4.H_2O$. Contains 30.5 percent Mn.

Manure

Term used traditionally for all types of plant nutrient sources including organic manures and fertilizers but now increasingly restricted to animal-dung-based bulky organic manures, composts, oilcakes, bone meal and other animal meals. See FYM and compost.

Micronutrients

Group name for essential plant nutrients B, Cl, Cu, Fe, Mn, Mo, Ni and Zn. These are required by plants in much smaller amounts than macronutrients but are equally essential. Also known as "minor elements". The glossary of the Soil Science Society of America defines them as nutrients found in concentrations of less than 100 ppm (0.01 percent) in plants and includes nine elements in the list, the above-listed elements and Co.

Mineral fertilizer

See fertilizer.

Multimicronutrient fertilizer

A fertilizer containing several micronutrients. Can be solid or liquid. Usually a physical mixture.

Municipal solid waste (MSW)

A mixture of domestic, small-scale industrial and demolition solid wastes generated within a community. About 80 percent of MSW is combustible and 82 percent of combustibles are of biological origin, hence, usable as raw material for composting.

Muriate of potash (MOP)

Same as potassium chloride. Derived from muriatic acid, the earlier name for hydrochloric acid.

Mycorrhiza

The term "mycorrhizae" (plural) means root fungus (from the Greek myces = fungus; rhiza = root). Symbiotic fungi that form a mutually beneficial association with plant roots. Mycorrhizae are of three types: (i) ectotrophic; (ii) endotrophic; and (iii) ectendotrophic. In ectomycorrhizae, a distinct fungal sheath develops on the root. In endomycorrhizae, fungal hyphae penetrate root cells. Relationship between mycorrhizae and plant roots is useful in improving the capability of plants for soil exploration and nutrient uptake. Mycorrhizae have special structures known as vesicles and arbuscules. The arbuscules help in the transfer of nutrients from the fungus to the root system, and the vesicles, which are "saclike" structures, store P as phospholipids. The survival and performance of VAM fungi is affected by the host plant, soil fertility, cropping practices, and biological and environmental factors. Maximum root colonization and sporulation occurs in low-fertility soils.

Neem cake

Residue left after extracting oil from neem seeds. A non-edible oilcake. Contains 5 percent N, 1 percent P_2O_5 and 1.5 percent K_2O. Used as an organic manure and also for coating urea, which helps to reduce the rate of nitrification and to protect applied N against losses.

Nitrate of soda

Chiefly the sodium and potassium salt of nitric acid containing not less than 15 percent nitrate-N and 10 percent potash (as K_2O).

Nitrophosphates

Products obtained by treatment of PR with nitric acid alone or in admixture with sulphuric or phosphoric acid, with or without subsequent treatment with ammonia. Their N is partly in ammoniacal and partly in nitrate form. Usually only a part of their P (30–85 percent) is water soluble, the remainder being citrate soluble. Also referred to as nitric phosphates or ammonium nitrate phosphates (ANP). Example: nitrophosphate grade 23–23–0. Typical internationally accepted technical specifications of this fertilizer specify a maximum moisture content of 1 percent by weight. Standard specifications of nitrophosphate (23–23–0) based on Indian experience are:

- moisture, percent by weight, maximum: 1.5;
- total N, percent by weight, minimum: 23.0;
- N in ammoniacal form, percent by weight, minimum: 11.5;
- N in nitrate form, percent by weight, maximum: 11.5;
- neutral ammonium citrate soluble phosphate (as P_2O_5), percent by weight, minimum: 23.0;
- water-soluble phosphate as P_2O_5, percent by weight, minimum: 18.5;
- calcium nitrate, percent by weight, maximum: 1.0;
- particle size: not less than 90 percent of the material shall pass through 4-mm IS sieve and be retained on 1-mm IS sieve. Not more than 5 percent of the material shall be below 1-mm IS sieve.

Non-acid-forming fertilizer

A fertilizer not capable of increasing the acidity or reducing the alkalinity of the soil. Example: calcium ammonium nitrate.

Oilcake

The residue left after oil has been extracted from an oilseed. Non-edible oilcakes can be used as manure, and edible oilcakes are used primarily as cattle feed. Example: groundnut cake. Having almost similar content of organic C but variable levels of N, P and K, oilcakes mineralize easily when added to soil. The C:N ratios in them are highly favourable for quick decomposition. Notwithstanding the alternative use of edible oilcakes as animal feed, both types of materials have been extensively used as organic fertilizers, either alone or in combination with mineral fertilizers.

Organic fertilizer

A fertilizer prepared from one or more processed materials of a biological nature (plant/animal) and/or unprocessed mineral materials (lime, PR, etc.) that have been altered through controlled microbial decomposition into a homogenous product with sufficient plant nutrients to be of value as a fertilizer. Usually contains a minimum of 5 percent nutrients (N + P_2O_5 + K_2O). Synonymous with organic manures and various types of composts but with greater degree of product standardization. Important carriers of all nutrients. Primary external sources of nutrients in organic farming. See compost.

Organic manure

A manure derived principally from substances of plant origin but sometimes also containing solid and liquid animal wastes. Partially humified and mineralized under the action of soil microflora, the organic manure acts primarily on the physical and biophysical components of soil fertility. A very broad term, it covers manures made from cattle dung, excreta of other animals, other animal wastes, rural and urban wastes, crop residues, and green manures. Concentrated organic manures, such as oilcakes, slaughterhouse wastes, fishmeal, guano and poultry manures are comparatively rich in NPK. The beneficial effects of organic manure go beyond the supply of nutrients – which in many instances is relatively small – by the enhancement of soil structure, water storage, CEC and biological activity. Interchangeable with organic fertilizers. Examples: compost and FYM. See also see compost, and organic fertilizer.

Peat

A dark brown or black plant residue produced by the partial decomposition and disintegration of mosses, sedges, trees and other plants. Commonly used as mixing material because of its water-retaining properties. Accepted as the best available carrier of biofertilizers. Indian peat contains 54 percent organic C, compared with 65 percent in Australian peat and 86 percent in American peat. Average composition of Indian peat is 54.2 percent C, 5.7 percent H and 1.5 percent N. It has a WHC of 149 percent, a bulk density of 2.18 g/cm^3, and a total surface area 647 m^2/g. Used in the preparation of organic fertilizers.

Phosphate-solubilizing micro-organisms (PSM)

Bacteria, fungi and actinomycetes that can solubilize insoluble forms of P. P-solubilizing bacteria (PSB) include *Bacillus megatherium* var. *phosphaticum, Bacillus polymyxa, Bacillus subtilis, Pseudomonas striata, Agrobacterium* sp., and *Acetobacter diazotrophicus*. P-solubilizing fungi (PSF) include *Aspergillus awamori, Penicillium digitatum, Penicillium bilaji*, and yeast (*Saccharomyces* sp.). P-solubilizing actinomycetes (PSA) include *Streptomyces* sp., and *Nocardia* sp. Generally, PSM secrete organic acids that dissolve insoluble phosphate. These microbes help in the solubilization of P from PR and other sparingly soluble forms of soil P by decreasing their particles size, reducing it to nearly amorphous forms. See also biofertilizer.

Phosphocompost

P-enriched compost. A type of enriched compost or fortified organic manure. It can be prepared through composting in which wastes are composted along with 12.5 or 25 percent suitable PR for 3–4 months. Preparation of one type of phosphocompost includes: crop waste 60 percent, animal dung 15 percent, FYM 2 percent, soil 2 percent, PR 15 percent, iron pyrites 5 percent, and urea 1 percent. Using an example from India, the following materials are needed to produce 1 000 tonnes phosphocompost on dry basis:

- 800 tonnes organic refuse, crop residues, leaves, grasses, weeds, etc.;
- 100 tonnes cattle dung or biogas slurry;
- 100 tonnes soil;
- 50 tonnes well-decomposed FYM/compost/ sewage sludge
- 265 tonnes suitable PR.

Their mixture is allowed to decompose in pits for three months. The contents are mixed together after 10, 20 and 45 days. Phosphocompost is ready in about three months. It contains 6–8 percent P_2O_5. During composting, about 50 percent of the insoluble P of the PR is converted into citrate-soluble P. This also provides a potential avenue for the gainful utilization of low-grade PR.

Potassium chloride (KCl)

Most common K fertilizer, contains 58–62 percent K_2O and about 48 percent Cl. Readily water soluble. Critical relative humidity of 84 percent at 30 °C. It has a higher salt index than potassium sulphate. Commercially called MOP. Typical internationally accepted technical specifications of particle size state that 95 percent of the material shall pass through 1.7-mm IS sieve and be retained on 0.25-mm IS sieve. Standard specifications of potassium chloride/MOP based on Indian experience are:

- moisture, percent by weight, maximum: 0.5;
- water-soluble potash (as K_2O), percent by weight, minimum: 60.0;
- sodium as NaCl, percent by weight (on dry basis), maximum: 3.5;
- particle size: minimum 65 percent of the material shall pass through 1.7-mm IS sieve and be retained on 0.25-mm IS sieve.

Potassium magnesium sulphate

A fertilizer providing K, Mg and S (22 percent K_2O, 11 percent Mg or 17 percent MgO and 22 percent S) all in plant-available form. Formula: $K_2SO_4.2MgSO_4$. It is a neutral salt as regards its effect on soil pH and contains less than 1.5 percent chloride. It should not be mixed with urea or CAN. Standard specifications of potassium magnesium sulphate based on Indian experience are:

- moisture, percent by weight, maximum: 0.5;
- potash content (as K_2O), percent by weight, minimum: 22.0;
- magnesium (as MgO), percent by weight, minimum: 18.0;
- sulphur (as S), percent by weight, minimum: 20.0;
- total chloride (as Cl), percent by weight (on dry basis), maximum: 2.5;

- sodium (as NaCl), percent by weight (on dry basis), maximum: 2.0.

Potassium sulphate (SOP)

An important source of K (50 percent K_2O) and S (18 percent), both in readily plant-available form. Formula: K_2SO_4. Particularly suitable for crops that are sensitive to chloride in place of potassium chloride. Very low salt index (46.1) compared with 116.3 in the case of MOP on material basis. It also stores well under damp conditions. SOP should not be mixed with CAN or urea. Typical internationally accepted technical specifications of SOP include maximum moisture content of 1 percent by weight and a maximum Na content as NaCl of 1.0 percent by weight. In addition, particle size specifications are that 90 percent of the material shall pass through 4-mm IS sieve and be retained on 1-mm IS sieve. Furthermore, not more than 5 percent material shall be below 1 mm in size. Standard specifications of potassium sulphate (SOP) based on Indian experience are:

- moisture, percent by weight, maximum: 1.5;
- potash (as K_2O), percent by weight, minimum: 50.0;
- sulphur (as S), percent by weight, minimum: 17.5;
- total chlorides (as Cl), percent by weight (on dry basis), maximum: 2.5;
- sodium (as NaCl), percent by weight (on dry basis), maximum: 2.0;

Precision farming

A farming system that uses GPS technology involving satellites and sensors on the ground and intensive information management tools to understand variations in resource conditions within fields. This information is used to apply fertilizers and other inputs more precisely and to predict crop yields more accurately.

Press mud

A by-product of sugar factories. Residue obtained by filtration of the precipitated impurities that settle out in the process of clarification of the mixed juice from sugar cane. Forms a cake of variable moisture content. The material has 55–75 percent moisture, is soft and spongy, light weight, amorphous and dark brown, and it can readily absorb moisture when dry. Depending on the process used in the sugar factory, it can be either sulphitation press mud or carbonation press mud. It contains 1.2 percent N, 2.1–2.4 percent P_2O_5, 2.0 percent K_2O, 238–288 ppm Zn and 112–132 ppm Cu. Material from factories using sulphitation process is a good source of S. Press mud from sugar factories using the carbonation process can find use as a liming material. Used as manure, as a soil amendment and as potential carrier of biofertilizer. Also known as filter cake, filter press cake, filter muck, mill mud, filter mud and filter press mud.

Prill

Spherical particle obtained by solidification of falling droplets of fertilizer during manufacture. Example: prilled urea.

Rhizobium biofertilizer

An artificially prepared *Rhizobium* culture used for seed dressing of legumes before sowing. A specific *Rhizobium* culture for a specific legume crop which has high ability for infection, nodulation, N_2 fixation and for which antibiotic resistance is needed. First commercial *Rhizobium* biofertilizer was produced as "Nitragin" in the United States of America in 1895.

Seaweeds

These are red, brown or green algae living in or by the sea. Agar agar is the product of red algae (*Rhodophyceae*). Seaweeds like *Ascophyllum nodosum*, *Laminaria digitata* and *Fucus serratus* contain gibberellin, auxins, cytokinin, etc. and are used as liquid organic fertilizer with or without fortification with minerals in many countries. Their role is more of a plant growth stimulant rather than of a nutrient supplier.

Sewage sludge

End product of the fermentation (aerobic or anaerobic) of sewage. Semi-solid product and a potential organic manure. Its general composition is 1.1–2.3 percent N, 0.8–2.1 percent P_2O_5 and 0.5–1.7 percent K_2O. It also contains Na, Ca, S, several micronutrients, toxic heavy metals, and Al. Usually, the concentration of most of these is higher in anaerobic than in aerobic sewage sludge.

Slow-release fertilizer

A fertilizer that is not readily soluble but releases its nutrients slowly over a period of time. Usually, some N fertilizers and micronutrient frits are slow release. Examples: isobutylidene diurea (IBDU), oxamide, and crotonylidene diurea (CDU). Similar to controlled-release fertilizers.

Slurry

Semi-liquid effluent from livestock sheds, consisting of urine and faeces, possibly diluted with water. Can be used as a fertilizer and as an ingredient during composting.

Soil amendment

A substance added to a poor soil to improve its fertility and more particularly its physico-chemical condition by alleviating excessive acidity, alkalinity, salinity, compactness, etc. Crop residues and bulky organic manures can be used as amendments to add nutrients and improve soil physical properties. An amendment usually incorporates plant nutrients. However, several soil amendments have a profound effect on the availability of P, Ca, Mg and micronutrients because of their effect on soil pH. Examples: lime for neutralizing excess soil acidity, and gypsum for reducing excess of alkalinity/sodicity.

Soil fertility

The component of soil productivity that deals with its available nutrient status, its ability to provide nutrients out of its own reserves for crop production and reactions with external nutrient additions. Its assessment is useful for deciding fertilizer application rates, which is the main function of soil testing laboratories. Fertilizers are needed where soil fertility is low and inadequate to support desired level of plant production. Aim of fertilizer application is to increase soil fertility. See also soil test.

Soil test

A rapid but reproducible measurement (usually chemical) made on a soil sample to assess its fertility status for a particular nutrient. Fertilizer recommendations when made for a specific field on the basis of soil tests are more balanced and more profitable than blanket/general recommendations. The higher the soil test value, the lower the fertilizer requirement and vice versa. A soil test has to be calibrated against crop response, which should result in a significant correlation before the soil test can be used for making fertilizer recommendations. Examples: Bray and Kurtz P_1 test for available P, DTPA – extractable test for Zn, and hot water extraction for available B. See also soil fertility.

Solution fertilizer

Liquid fertilizer free of solid particles. See also liquid fertilizers.

Straight fertilizer

A traditional term referring to fertilizers that contain (and are used for) one major nutrient (traditionally N, P or K) as opposed to multinutrient fertilizers. For secondary nutrients, products containing elemental S, magnesium sulphate, calcium oxide, etc. In micronutrients, borax, Zn or Fe chelates and sulphate salts of micronutrients are straight fertilizers, although the phrase is not often used for micronutrient carriers. Not a straightforward term because many “straight fertilizers” also contain other essential plant nutrients, such as S.

Sulphate of potash (SOP)

See potassium sulphate.

Sulphur bentonite

An elemental S product in which 10–15 percent bentonite clay is included during manufacturing for ease in granulation, pastille formation, handling and application. Materials with a range of particle size, hence, decomposition rates are variable. Agronomic efficiency not very different from that of elemental S.

Superphosphate

Class of fertilizers obtained by reacting PR with sulphuric acid or with phosphoric acid. Common types are single superphosphate (SSP) containing 16 percent P_2O_5

and 11–12 percent S, and triple superphosphate (TSP) containing 46 percent P_2O_5 and little S.

Suspension fertilizer

A two-phase fertilizer in which solid particles are maintained in suspension in the aqueous phase. A type of liquid fertilizer. Addition of a clay attapulgite facilitates keeping its constituents in suspension form. See also liquid fertilizers.

Toxicity

Adverse reaction of plants caused by certain constituents in the soil or water that are taken up by the plants and accumulated to high concentration. This results in plant damage, reduced yields or even death of plants. The degree of plant damage depends on the element, its uptake, concentration in the plant tissue and the sensitivity of the crop.

Triple superphosphate (TSP)

A fertilizer obtained by treating PR with phosphoric acid and containing about 46 percent P_2O_5, mainly in water-soluble form. Unlike SSP, it contains little S.

Urban compost

Compost prepared from urban and industrial wastes, city garbage, sewage sludge, etc. Its typical composition is 1.5–2.0 percent N, 1.0 percent P_2O_5 and 1.5 percent K_2O. Commercially prepared urban compost has been reported to contain 1 percent Fe, about 375 ppm Cu, 705 ppm Zn, 740 ppm Mn and small amounts of other micronutrients. Also termed town compost (as opposed to rural compost). See also compost.

Urea

A white, crystalline, non-protein organic N compound made synthetically from ammonia and CO_2. First synthesized by Wholer in 1928. Formula: $CO(NH_2)_2$. This non-electrolyte compound contains readily water-soluble 46 percent N, all in amide (NH_2) form. Most concentrated solid N fertilizer. Produced as prills or granules of varying sizes. It is hydrolysed in the soil by the enzyme urease to furnish ammonium and then nitrate ions. Used as solid N fertilizer for soils, for foliar application and as an ingredient of NP/NPK complexes. Leaves behind an acidic effect in soils. Sometimes fortified with Zn and Fe.

$$\text{Urea} \xrightarrow{\text{urease}} \text{Ammonium carbamate} \longrightarrow \text{Ammonia}$$

Vermicompost (also wormicompost)

An important type of compost and organic fertilizer that contains earthworm cocoons, excreta, beneficial micro-organisms, actinomycetes, plant nutrients, organic matter, enzymes, hormones, etc. An organic fertilizer produced by earthworms and containing on an average 0.6 percent N, 1.5 percent P_2O_5 and 0.4 percent K_2O. In addition to NPK, it is also a source of micronutrients, having an average of 22 ppm Fe, 13 ppm Zn, 19 ppm Mn and 6 ppm Cu. A product of variable composition. Vermicomposting is an appropriate technique for the disposal of non-toxic solid and liquid organic wastes. It helps in cost-effective and efficient recycling of animal wastes (poultry, horse, piggery excreta and cattle dung), agricultural residues and industrial wastes using low energy. It improves soil health, and, thus, productivity.

Zinc sulphate

Common Zn-containing fertilizer. Produced as $ZnSO_4.7H_2O$ (21 percent Zn) or $ZnSO_4.H_2O$ (33 percent Zn). Used for soil or foliar application. Also provides S. Standard specifications of zinc sulphate heptahydrate based on Indian experience are:

- zinc (as Zn), percent by weight, minimum: 21.0;
- sulphur (as S), percent by weight, minimum: 10.0;
- cadmium (as Cd), percent by weight, maximum: 0.0025;
- arsenic (as As), percent by weight, maximum: 0.01;
- lead (as Pb), percent by weight, maximum: 0.003;
- copper (as Cu), percent by weight, maximum: 0.1;
- magnesium (as Mg), percent by weight, maximum: 0.5;
- matter insoluble in water, percent by weight, maximum: 1.0;
- pH: not less than 4.0.

For a more detailed glossary

FAO–FDCO integrated nutrient management – a glossary of terms by Tandon and Roy (2004) (also available at http://www.fao.org.landandwater/agll/ipns/index_en.jsp).

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Units and conversion factors

UNITS

1 metre (m) = 100 centimetres (cm) (1.0936 yards)
1 kilometre (km) = 1 000 m (kilo = thousand)
1 litre = 1 000 cubic centimetres (cc) or 1 000 millilitres (ml)
1 milligram (mg) = 1 000 micrograms (µg)
1 gram (g) = 1 000 mg
1 kilogram (kg) = 1 000 g (2.20 pounds (lb))
1 quintal = 100 kg (0.1 tonne)
1 tonne = 1 000 kg
1 hectare (ha) = 10 000 m^2 (2.471 acres)
1 percent = 1 part in 100 parts (1% = 10 000 ppm)
ppm = mg/kg or mg/litre or µg/g
1 bushel wheat (USA) = 27.215 kg
1 bushel maize (USA) = 25.410 kg

Conversion from non-SI unit to SI units

Non-SI unit	Multiply by *	To obtain SI unit
Length		
Inch	2.54	centimetres, cm (100 cm = 1 m)
Foot	0.304	metre, m
Yard	0.9144	metre, m
Statute mile	1.6093	kilometre, km
Area		
Acre	0.405	hectare, ha (10 000 m^2 = 1 ha)
Square foot	9.29×10^{-2}	square metre, m^2
Volume		
Bushel	35.24	litre
Cubic foot	2.83×10^{-2}	cubic metre, m^3
Cubic inch	2.83×10^{-2}	cubic metre, m^3
Gallon (USA)	3.78	litre
Mass		
Ounce (avdp.)	28.4	gram
Pound	0.454	kilogram, kg (10^3 g)
Hundredweight	50.8023	kilogram, kg
Long ton	1.1065	tonne
Short ton	0.90781	tonne
Yield and rate		
Bushel per acre wheat (60 lb)	67.19	kilograms per hectare, kg/ha
Bushel per acre maize (56 lb)	62.71	kilograms per hectare, kg/ha
Bushel per acre barley (48 lb)	53.75	kilograms per hectare, kg/ha
Gallon per acre (USA)	9.35	litres per hectare, litres/ha
Pounds/acre	1.121	kilograms per hectare, kg/ha

* To convert from SI to non-SI units, divide by the factor given.

Conversion from non-SI unit to SI units (Continued)

Non-SI unit	Multiply by *	To obtain SI unit
Pressure		
Atmosphere	0.101	megaPascal, MPa (10^6 Pa)
Bar	0.1	megaPascal, MPa
Temperature		
Degrees Fahrenheit (°F - 32)	0.556	degrees, °C
Energy		
British thermal unit (BTU)	1.05×10^3	joule, J
Calorie	4.19	joule, J

* To convert from SI to non-SI units, divide by the factor given.

Other conversion factors (nutrients)

From	To	Multiply by	From	To	Multiply by
N	Protein	6.25			
P	P_2O_5	2.29	P_2O_5	P	0.436
K	K_2O	1.20	K_2O	K	0.83
Ca	CaO	1.40	CaO	Ca	0.715
Mg	MgO	1.66	MgO	Mg	0.603
S	SO_4	3.0	SO_4	S	0.33
S	SO_3	2.5	SO_3	S	0.44

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